How to view this month's annular **ECLIPSE** p. 46

JUNE 2021

Astronomy®

The world's best-selling astronomy mag

EARTH IS A PLANET TOO!

How we learn about other worlds from the ground beneath our feet p. 16

» A new age for gravitational waves and cosmic rays p. 24

PLUS

The sky's best planetary nebulae p. 50

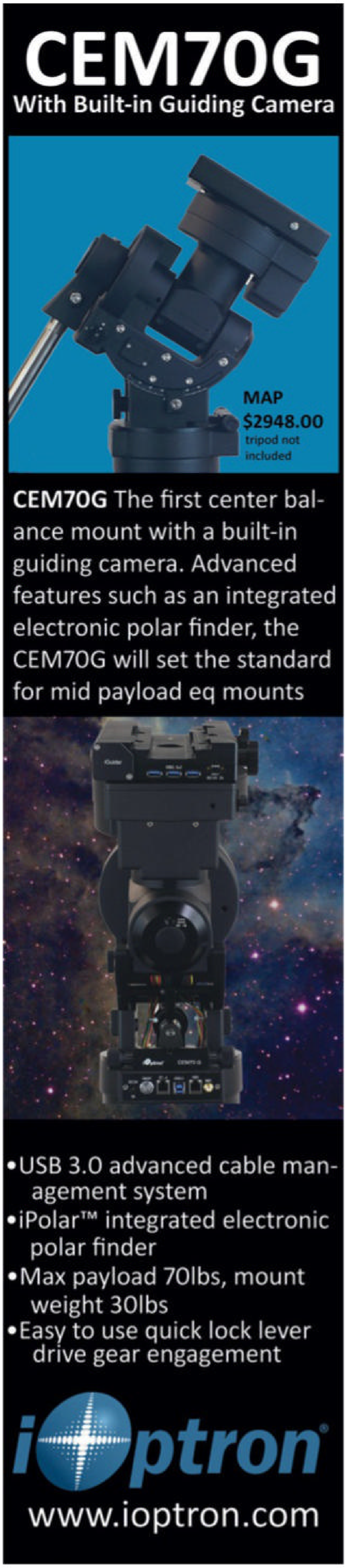
Astronomy with a small scope p. 40

Bob Berman on observing accessories p. 13

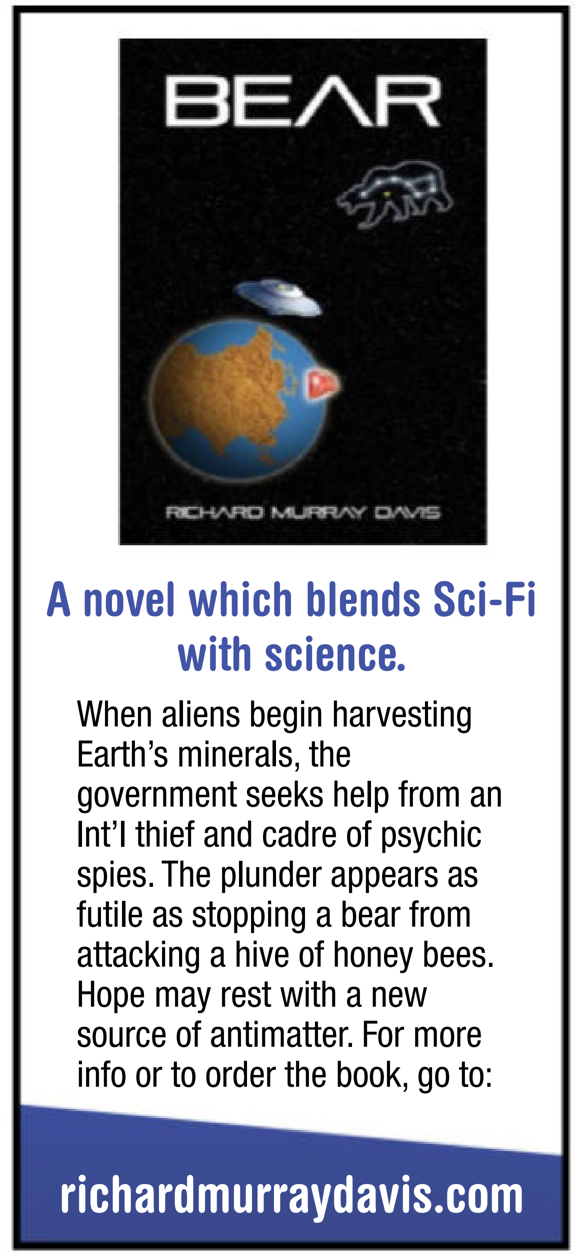
www.Astronomy.com

BONUS ONLINE CONTENT CODE p. 4

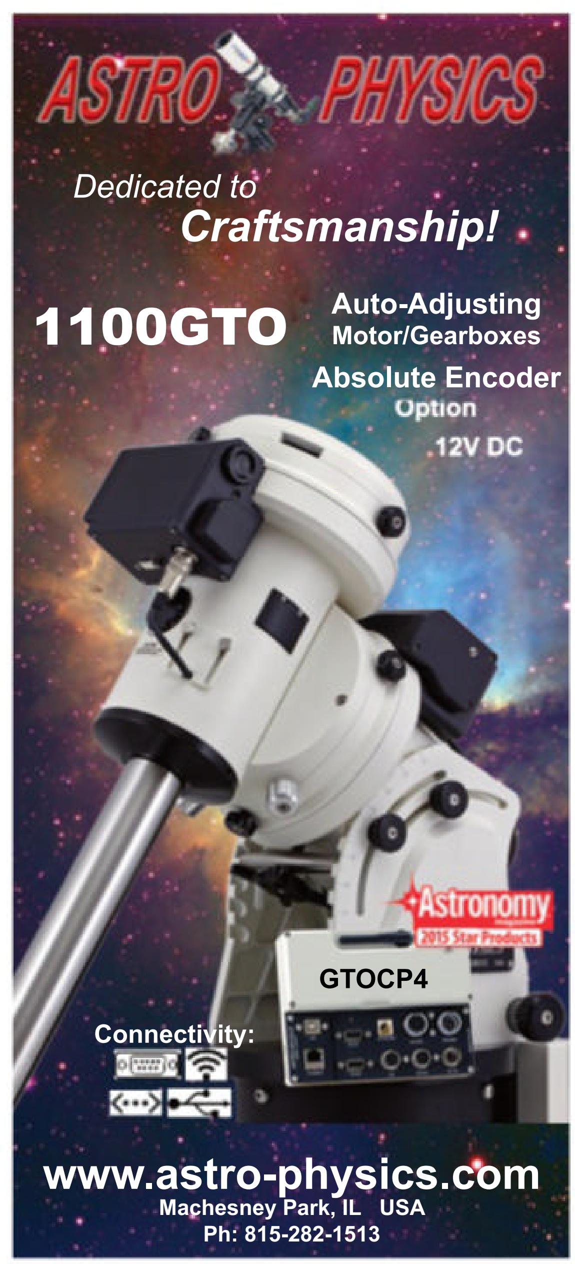
Vol. 49 • Issue 6

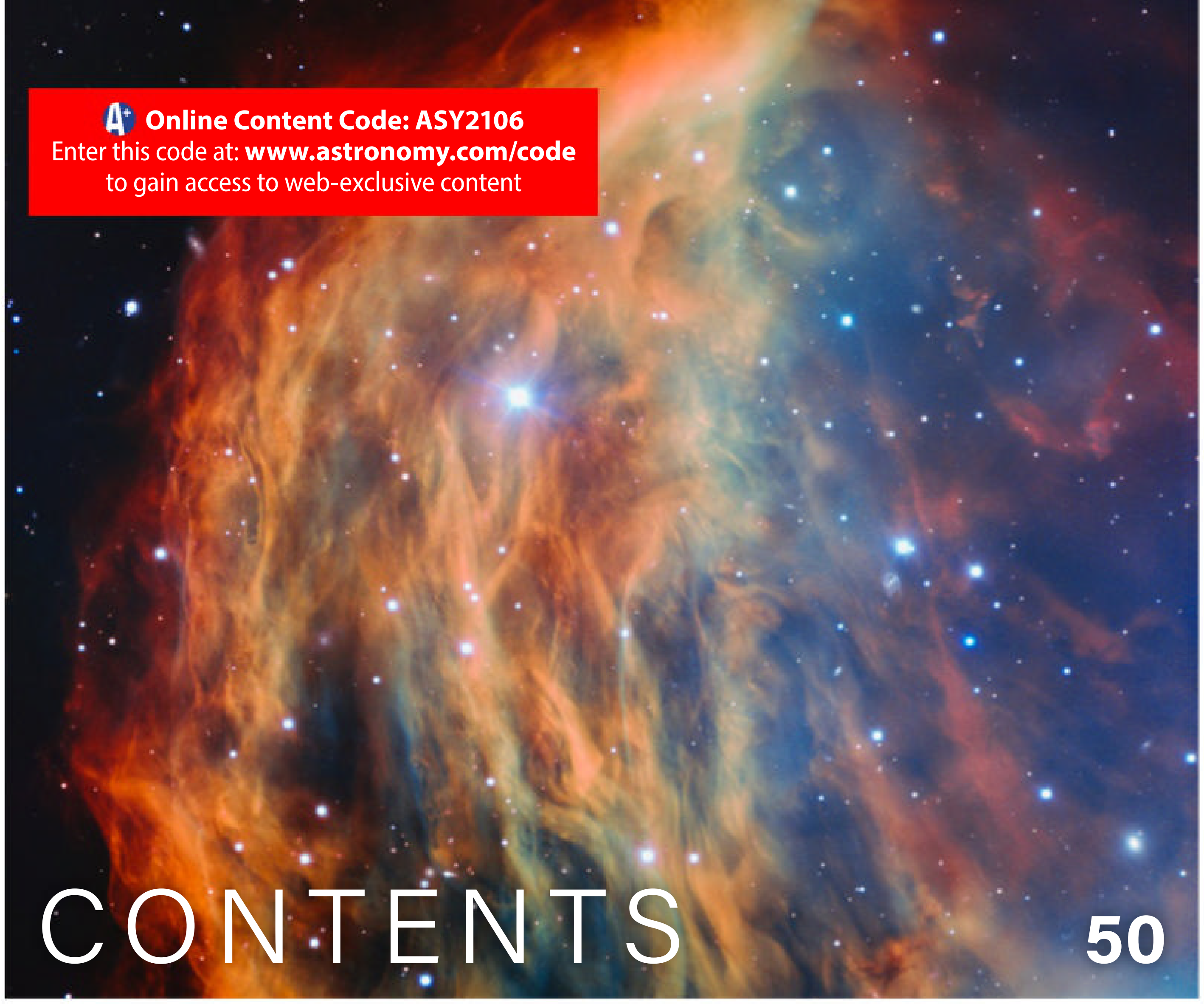

CEM70G
With Built-in Guiding Camera
MAP
$2948.00
tripod not included
CEM70G The first center balance mount with a built-in guiding camera. Advanced features such as an integrated electronic polar finder, the CEM70G will set the standard for mid payload eq mounts
•USB 3.0 advanced cable management system
•iPolar™ integrated electronic polar finder
•Max payload 70lbs, mount weight 30lbs
•Easy to use quick lock lever drive gear engagement
ioptron
www.ioptron.com


ScopeBuggy
• For use with most tripods, DOBs and piers
• 10” Pneumatic tires for soft ride
• Load tested to 600+ pounds
• Assemble & disassemble in minutes
• Adjustable rear axle height (1½” to 7”)
• Ideal for scopes up to 36”
• One person can quickly and easily move any sized scope
Still #1
$345.00*
Plus S&H
Approx. $60 Shipping USA
*Subject to change
Patent Pending
SCOPEBUGGY
P.O. BOX 834
Elephant Butte, NM
87935
915-443-9010
www.ScopeBuggy.com


BEAR
RICHARD MURRAY DAVIS
A novel which blends Sci-Fi with science.
When aliens begin harvesting Earth’s minerals, the government seeks help from an Int’l thief and cadre of psychic spies. The plunder appears as futile as stopping a bear from attacking a hive of honey bees. Hope may rest with a new source of antimatter. For more info or to order the book, go to:
richardmurraydavis.com


The best $299 eyepiece you’ll ever buy.
No computer required. Battery-powered 7” color monitor included.
DIGITAL CCD CAMERA
M16 Eagle Nebula
8” Celestron Evolution
Metropolitan Skies
REVOLUTION IMAGER
RevolutionImager.com
High Point Scientific
Agena AstroProducts
Oceanside Photo & Telescope
Woodland Hills Telescope
Skies Unlimited
Orange County Telescope


ASTRO-PHYSICS
Dedicated to
Craftsmanship!
1100GTO
Auto-Adjusting
Motor/Gearboxes
Absolute Encoder
Option
12V DC
Astronomy
2015 Star Products
GTOCP4
Connectivity:
www.astro-physics.com
Machesney Park, IL USA
Ph: 815-282-1513

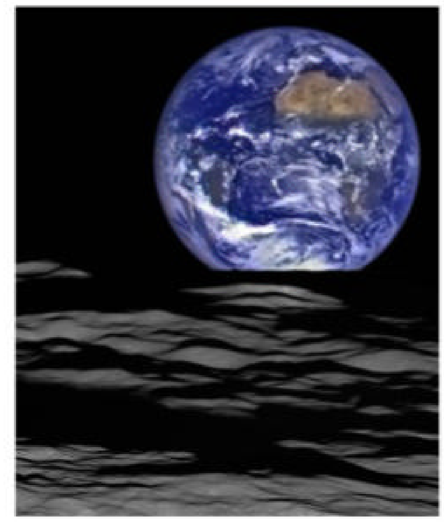


Online Content Code: ASY2106
Enter this code at: www.astronomy.com/code
to gain access to web-exclusive content

CONTENTS

50

JUNE 2021
VOL. 49, NO. 6



ON THE COVER
Our own planet Earth gives us great insight into the worlds of planetary science. NASA/GSFC/ARIZONA STATE UNIVERSITY

FEATURES

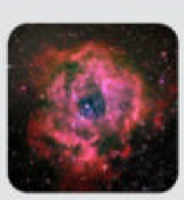
COLUMNS

IN EVERY ISSUE

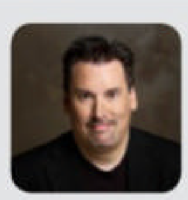
ONLINE FAVORITES

Go to **www.Astronomy.com** for info on the biggest news and observing events, stunning photos, informative videos, and more.

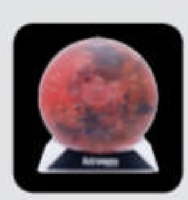
Globes
From Mercury to Pluto, get the hottest globes around.



Picture of the Day
Gorgeous photos from our readers.



Dave's Universe
The inside scoop from the editor.



My Science Shop
Perfect gifts for your favorite science geeks.

Astronomy (ISSN 0091-6358, USPS 531-350) is published monthly by Kalmbach Media Co., 21027 Crossroads Circle, P. O. Box 1612, Waukesha, WI 53187–1612. Periodicals postage paid at Waukesha, WI, and additional offices. POSTMASTER: Send address changes to *Astronomy*, PO Box 8520, Big Sandy, TX 75755. Canada Publication Mail Agreement #40010760.

Earth is a planet too!

Because it's our home, we seldom think of Earth in terms of planetary science. But it has much to teach us about other worlds. NASA

Many years ago, in the hallways at AstroMedia Corp., our then-editor Richard Berry had a saying. When one of the team questioned whether we should be covering earth science, Richard snapped back with, "Earth is a planet too!" And of course, he was right.

As we walk around on Earth, sometimes we overlook what a perfect laboratory it is for understanding planetary science. Earth gives us the greatest insight we have into the formation and evolution of rocky planets in the solar system. As much as we look outward toward Mars to build a picture of the solar system's past, perhaps of the rarity or commonality of life itself, we also look inward at Earth in many ways.

Senior Associate Editor Alison Klesman's story on page 16 details the latest research on Earth as a planet, and how that research is shedding light on the formation and evolution of Mars and Mercury and Venus. Geologists and planetary scientists can decipher much about our brethren by "reading the rocks under our feet," as the saying goes, and extrapolating that knowledge to nearby worlds.

Reading the rocks is only the start, however. NASA satellites study Earth's atmospheric patterns and behavior closely; not only does that help us with weather prediction, but it also allows researchers to understand climate and how it reveals what's happening atmospherically on the other rocky planets. The work even applies to modeling and comprehending weather patterns on the gas giants and out to far-away exoplanets.

"Earth is a planet too" has deepened as a slogan over the years, as almost 30 Earth-based space missions now look down onto our planet, analyzing it in nearly every way possible. NASA's earth science budget is enormous, and the benefits we gain in our everyday world are enormous, telling us practically everything we'd like to know about the only known world that supports life.

Yours truly,

David J. Eicher

Let me underscore a change that has just taken place for subscribers: If you're a subscriber to the print edition of this magazine, your subscription now includes access to the digital edition of the magazine. This change took place with the April 2021 issue. To access digital editions, check Zinio.com and download the Zinio app. As a subscriber, you're also already eligible to view subscriber-only content on Astronomy.com. This includes such features as the online star atlas, picture of the day, and many more.

Follow the Dave's Universe blog: **www.Astronomy.com/davesuniverse**
Follow Dave Eicher on Twitter: **@deicherstar**

FOLLOW *ASTRONOMY*

facebook.com/AstronomyMagazine
twitter.com/AstronomyMag
youtube.com/user/AstronomyMagazine
instagram.com/astronomy.magazine

Astronomy

Editor David J. Eicher
Design Director LuAnn Williams Belter

EDITORIAL
Senior Editor Mark Zastrow
Production Editor Elisa R. Neckar
Senior Associate Editor Alison Klesman
Associate Editor Jake Parks
Associate Editor Caitlyn Buongiorno
Editorial Assistant Hailey McLaughlin

ART
Illustrator Roen Kelly
Production Specialist Jodi Jeranek

CONTRIBUTING EDITORS
Michael E. Bakich, Bob Berman, Adam Block, Glenn F. Chaple Jr., Martin George, Tony Hallas, Phil Harrington, Korey Haynes, Jeff Hester, Alister Ling, Stephen James O'Meara, Martin Ratcliffe, Raymond Shubinski, Richard Talcott

EDITORIAL ADVISORY BOARD
Buzz Aldrin, Marcia Bartusiak, Jim Bell, Timothy Ferris, Alex Filippenko, Adam Frank, John S. Gallagher III, Daniel W. E. Green, William K. Hartmann, Paul Hodge, Edward Kolb, Stephen P. Maran, Brian May, S. Alan Stern, James Trefil

Kalmbach Media
Chief Executive Officer Dan Hickey
Senior Vice President, Finance Christine Metcalf
Senior Vice President, Consumer Marketing Nicole McGuire
Vice President, Content Stephen C. George
Vice President, Operations Brian J. Schmidt
Vice President, Human Resources Sarah A. Horner
Senior Director, Advertising Sales and Events David T. Sherman
Advertising Sales Director Scott Redmond
Circulation Director Liz Runyon
Director of Digital Strategy Angela Cotey
Director of Design & Production Michael Soliday
Retention Manager Kathy Steele
Single Copy Specialist Kim Redmond

ADVERTISING DEPARTMENT
Phone (888) 558-1544
Ad Production AdServices@Kalmbach.com
Dina Johnston, djohnston@kalmbach.com

RETAIL TRADE ORDERS AND INQUIRIES
Selling *Astronomy* magazine or products in your store:
Phone (800) 558-1544
Outside U.S. and Canada (262) 796-8776, ext. 818
Fax (262) 798-6592
Email tss@kalmbach.com
Website www.Retailers.Kalmbach.com

CUSTOMER SALES AND SERVICE
Phone (877) 246-4835
Outside U.S. and Canada (903) 636-1125
Customer Service customerservice@AstronomyMagazine.info

CONTACT US
Ad Sales adsales@astronomy.com
Ask Astro askastro@astronomy.com
Books books@astronomy.com
Letters letters@astronomy.com
Products products@astronomy.com
Reader Gallery readergallery@astronomy.com
Editorial Phone (262) 796-8776

For reprints, licensing, and permissions:
PARS International at www.parsintl.com

Voyager 2 launched over 40 years ago.
NASA/ESA/G. BACON/STSCI

We welcome your comments at Astronomy Letters, P.O. Box 1612, Waukesha, WI 53187; or email to ***letters@astronomy.com****. Please include your name, city, state, and country. Letters may be edited for space and clarity.*

Voyager 2 slingshot

I was reading the article from the December issue, "The mystery and majesty of the ice giants," and I think I came across an error. If the decision to direct Voyager 2 to the ice giants was made in 1981, which was also the year it flew by Saturn, wouldn't it be Saturn that Voyager got the slingshot "kick" from, not Jupiter as stated? I realize it received a slingshot from both, but in the context of what was being said there, it was Saturn that was utilized for the final directing towards Uranus and Neptune. **— Matt Skinner,** Livermore, CA

Associate Editor Caitlyn Buongiorno answers: *Three years before launch, the planners proposed that if Voyager 1 was successful, Voyager 2 would be redirected to Uranus and Neptune, taking advantage of a rare planetary alignment. The Jupiter flyby was the start of Voyager 2's eventual journey to the ice giants. At Jupiter, Voyager 2 received the "kick" necessary to send it on to Saturn, but in order to ensure Neptune and Uranus were still possible targets, that kick also altered the spacecraft's trajectory. (Saturn did supply a final push to carry Voyager 2 to Neptune and Uranus, though.)*

Observing advice

Another great Strange Universe column in the February issue: Bob Berman elicited additions to his top 10 telescopic challenges. I'd suggest splitting the double star of Antares, which, when successful, shows a blazing orange-red star and a dotlike green companion. I've done it with a 10.24-inch Vixen VMC scope at 31 degrees north latitude. **— Eric Rachut,** Moody, TX

A tale of two sciences

Since October, I have been meaning to say how much I enjoyed Alan Goldstein's article "View Earth through a cosmic lens." The idea of juxtaposing the time frame of geology with objects viewed by astronomers created a previously unconsidered relationship between the two sciences for me. This article has caused me to think about the time frame that connects Earth with the cosmos in a totally new way. **— Bonnie Becker,** Springfield, VA

SNAPSHOT

PROBE PEERS UNDER VENUS' ATMOSPHERE

NASA mission gets an unexpectedly revealing view of our neighboring planet.

The Parker Solar Probe is on a seven-year journey to get up close and personal with the Sun. On its way, it's making regular flybys of Venus, using the planet's gravity to direct the probe's orbit closer to our star. Its wide-field camera captured this view of Venus' nightside during its third flyby, in July 2020, at a mere 7,700 miles (12,400 kilometers) from the planet.

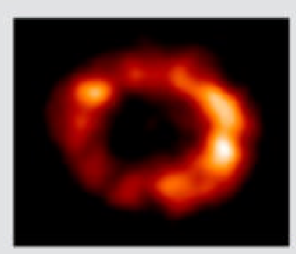
From its position above the thick venusian clouds, the NASA craft detected a fluorescent rim around the edge of Venus. But the team was stunned to see that the image also captured a surface feature: a prominent dark area in the center of the planet, known as Aphrodite Terra.

The Wide-field Imager for Parker Solar Probe (WISPR) is designed to image the Sun's corona and inner heliosphere in visible light. That's why the team was surprised the camera was able to peer straight to Venus' surface rather than imaging just its cloudy atmosphere. This may be a sign that WISPR is more sensitive to near-infrared light than predicted. If so, the instrument could be used to study dust around the inner solar system and Sun. Alternatively, the imager may instead have discovered a "window" in Venus' atmosphere through which light can escape. – CAITLYN BUONGIORNO

NASA/JOHNS HOPKINS APL/NAVAL RESEARCH LABORATORY/GUILLERMO STENBORG AND BRENDAN GALLAGHER. BOTTOM FROM LEFT: NOIRLAB/NSF/AURA/J. DA SILVA; CHANDRA (X-RAY): NASA/CXC/UNIV. DI PALERMO/E. GRECO, NUSTAR (X-RAY): NASA/JPL-CALTECH; DESY, SCIENCE COMMUNICATION LAB

» HOT BYTES

APTLY NAMED
Astronomers have confirmed the orbit of 2018 AG37, the most distant object ever observed in the solar system. Nicknamed "Farfarout," the 250-mile-wide (400 kilometers) planetoid is currently at 132 times the Earth-Sun distance, or nearly four times farther from the Sun than Pluto.



NEWBORN PULSE
Energetic X-rays emerging from the remnant of supernova SN 1987A suggest that a pulsar — a rapidly spinning neutron star emitting beams of radio waves — lies hidden in the debris. If confirmed, it would be the youngest pulsar ever found.

LAST GASP
The IceCube neutrino detector at the South Pole has captured a neutrino — a tiny, chargeless particle — emitted when a star was ripped apart and swallowed by a supermassive black hole 700 million light-years away. It's the first neutrino observed from such an event.

A NEARBY EXOPLANET WITH AN EARTH-LIKE ATMOSPHERE

THIN AIR. Though Gliese 486b's landscape is likely hot and hellish, its atmosphere may resemble Earth's in its thinness.
RENDERAREA, HTTPS://RENDERAREA.COM

» Today, astronomers know of thousands of planets orbiting other stars. But relatively few of these worlds are considered Earth-like.

Among those that are, studying their atmospheres is difficult because rocky planets have only a thin envelope of air surrounding them. Thus, Earth-like atmospheres must meet stringent criteria to render them observable, even with upcoming telescopes like NASA's James Webb Space Telescope or the next generation of extremely large ground-based telescopes.

But a newly discovered rocky super-Earth 26 light-years away could fit the bill. The planet, dubbed Gliese 486b, was identified by members of the CARMENES (Calar Alto high-Resolution search for M dwarfs with Exoearths with Near-infrared and optical Échelle Spectrographs) consortium. Further scrutiny revealed the planet is 2.8 times more massive and 30 percent larger than Earth.

Gliese 486b orbits an M dwarf, a star smaller and cooler than the Sun. However, the planet's tight orbit — which takes just 1.5 days at an average distance of 1.6 million miles (2.6 million kilometers) — means it receives intense radiation from its star. The planet is also tidally locked, so one side perpetually faces its sun. Researchers think its surface temperature averages around 800 degrees Fahrenheit (430 degrees Celsius), meaning Gliese 486b's surface probably looks similar to Venus.

But, unlike the dense atmosphere of Venus, Gliese 486b's atmosphere is probably thin, a result of the star's radiation blasting away atmospheric molecules, despite the best efforts of the planet's gravity to retain them. Coupled with its proximity to Earth, that makes Gliese 486b an exciting target for future telescopes to observe. By studying such worlds, researchers hope to better understand how terrestrial planets like Earth form — and subsequently lose or retain — their atmospheres. —ALISON KLESMAN

STELLAR TANTRUM

ESA/HUBBLE & NASA, B. NISINI

Stellar nurseries are scattered throughout the Milky Way. Inside these clouds of gas and dust, dense regions of matter condense until finally collapsing to form a protostar. Leftover material then creates a rotating, flattened disk around the fledgling star. At this stage, material is still raining down on the hungry star. The star's feeding frenzy can eject additional superheated matter far into space. In this image, a central newborn star is blowing out gas and dust to distances of around 10 light-years at speeds of over 93 miles (150 kilometers) per second. Bright shock waves, referred to as Herbig-Haro objects, are seen where those outflows strike the surrounding gas in the nebula. – C.B.

ESA/HUBBLE & NASA, J. LEE AND THE PHANGS-HST TEAM; ACKNOWLEDGMENT: JUDY SCHMIDT

People are strange, galaxies are stranger

The Black Eye galaxy casts its inscrutable gaze over the dark, mysterious cosmos. Located 17 million light-years away, the galaxy — also known as NGC 4826 — appears to be rotating strangely. The gas in its inner regions is spinning in one direction, while gas on the galaxy's outskirts twists the opposite way. And, at the boundary between the two, colliding gas gives birth to new stars. What caused this mysterious motion? Astronomers believe a recent galactic merger might be responsible for this strange sight. — HAILEY ROSE MCLAUGHLIN

QUICK TAKES

GRAVITY GANG

The globular cluster NGC 6397 might be home to a collection of many stellar-mass black holes rather than a single intermediate-mass black hole, as astronomers had previously suspected.

DESERVED RECOGNITION

NASA has named their headquarters building in Washington, D.C., after Mary W. Jackson, a pioneering "human computer" who became the agency's first Black female engineer.

DARK MATTER BEASTS

A new model could explain how supermassive black holes grew so quickly after the Big Bang. Instead of black holes slowly accreting the remnants of stars, these monsters instead may form when a massive clump of dark matter at the core of a galaxy collapses.

TURKEY'S TIME

Turkish President Recep Tayyip Erdoğan announced the country will launch a lunar rover in 2023 as part of a new 10-year plan to develop its space program. The nation's goals also include sending astronauts to orbit.

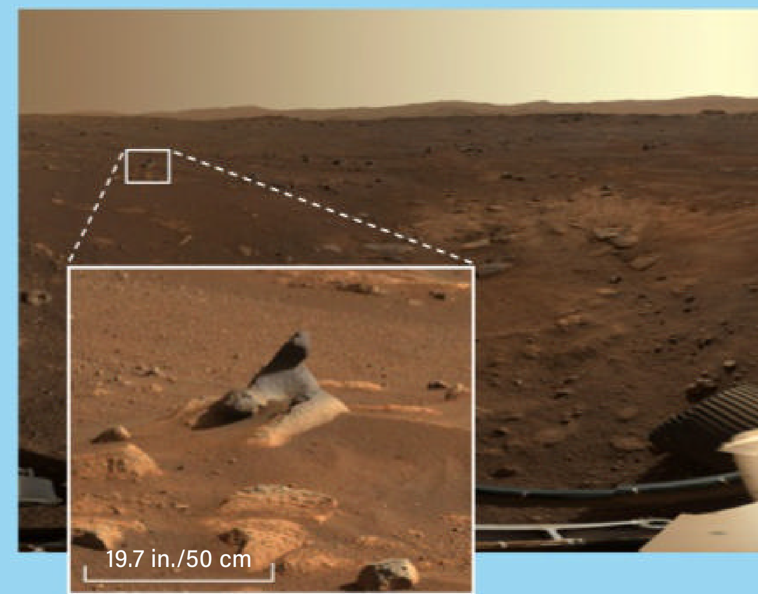
BOSON BUDDIES

Astronomers have proposed that a 142-solar-mass black hole recently detected via gravitational waves could have formed through a collision of two boson stars. These exotic — and for now, purely theoretical — stars are made of ultralight particles just one-billionth the mass of an electron. They are also an appealing candidate for dark matter.

ARTEMIS LIVES

The Biden administration has declared it supports NASA's commitment to returning American astronauts to the Moon as part of the Artemis Program, which will serve as a stepping-stone to Mars.

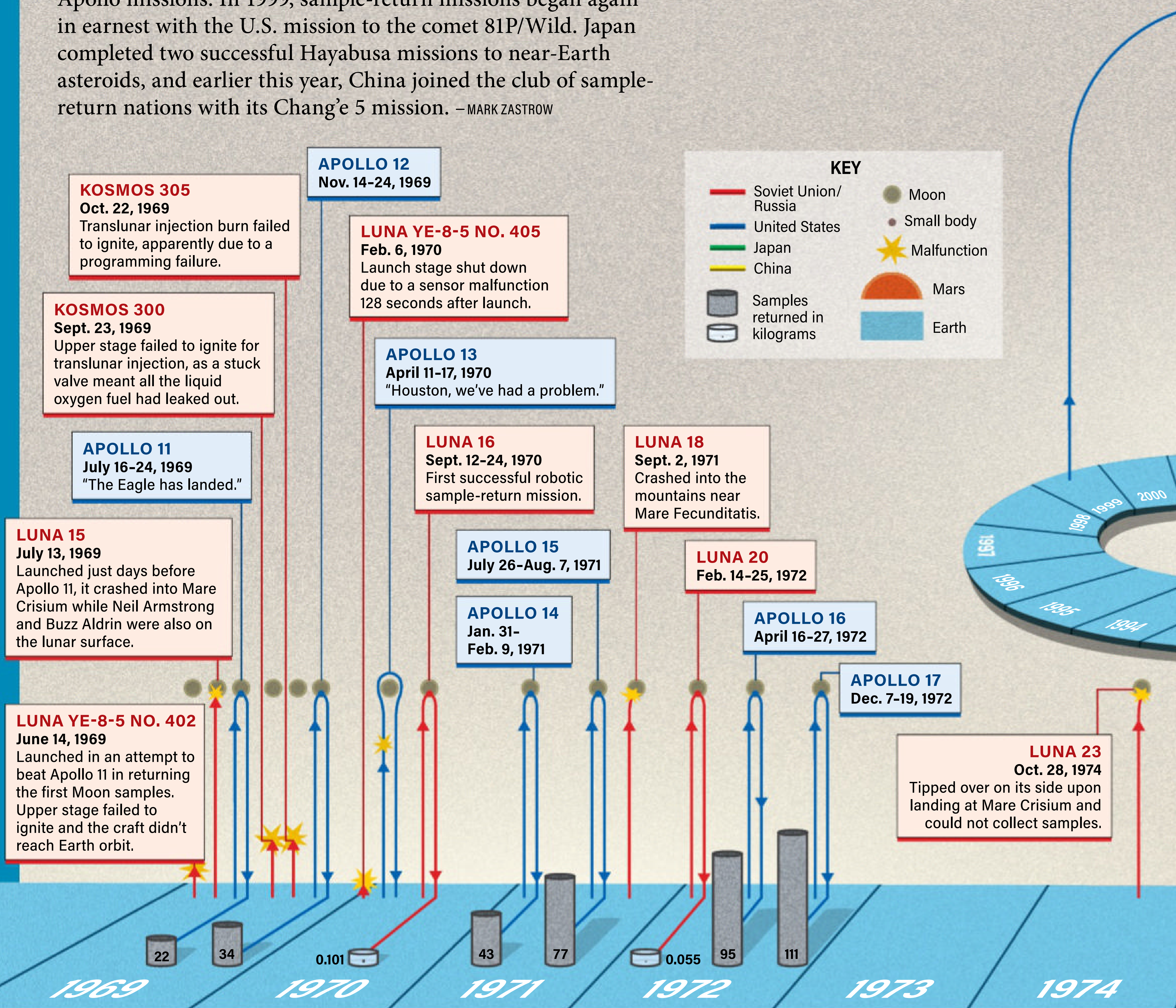
— JAKE PARKS



BRING IT BACK HOME

Precious cargo. Intrepid probes that return pictures and data are great; even better is when they return samples that scientists can analyze with lab equipment on Earth. But while astronauts could pick up and haul hundreds of pounds, robotic probes are limited to just a handful of pounds — or even just specks of dust from the wispy atmospheres of comets or asteroids.

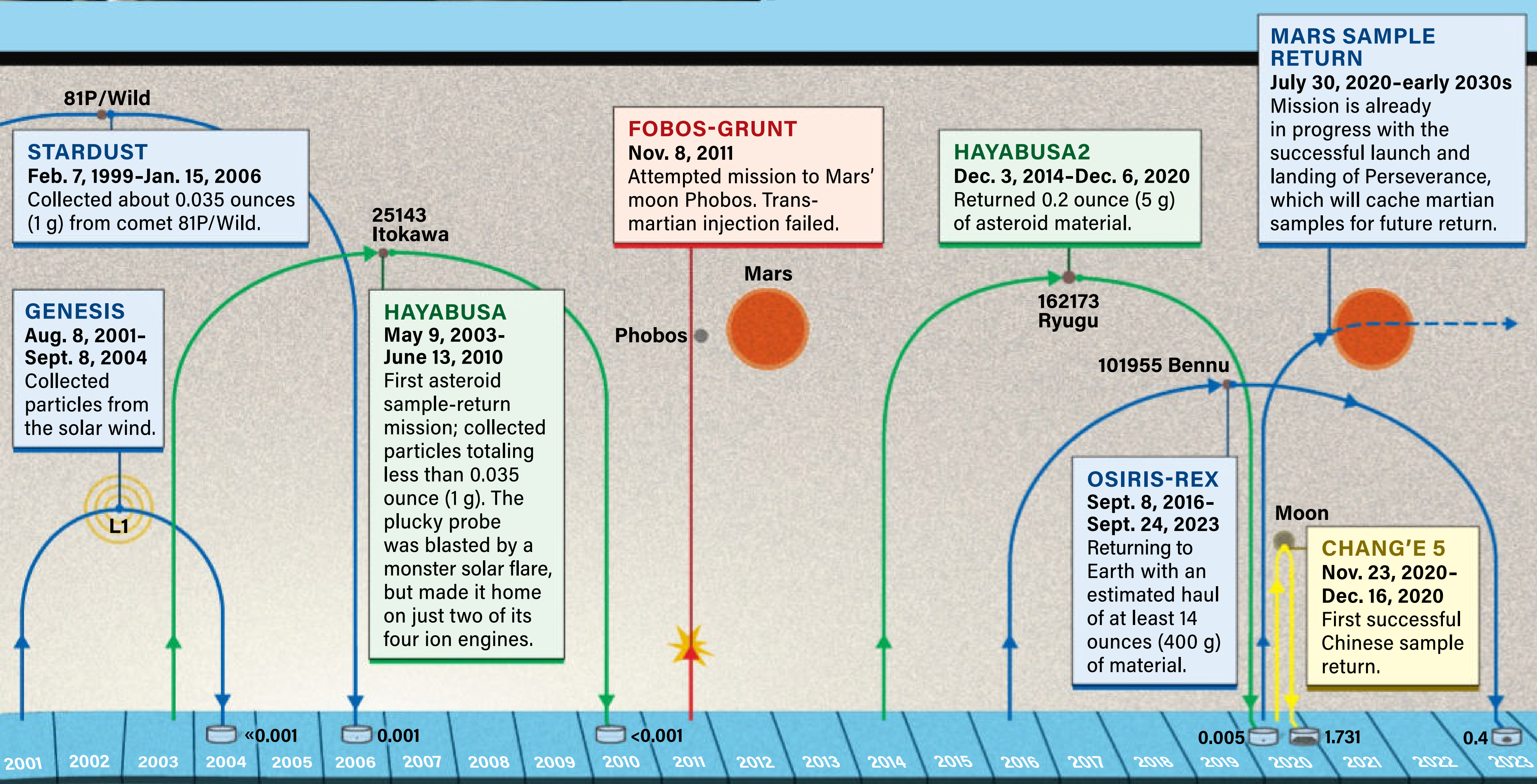
The history of deep-space sample-return missions began during the Space Race in the 1960s and '70s, when Soviet robotic probes raced (and nearly beat) the American crewed Apollo missions. In 1999, sample-return missions began again in earnest with the U.S. mission to the comet 81P/Wild. Japan completed two successful Hayabusa missions to near-Earth asteroids, and earlier this year, China joined the club of sample-return nations with its Chang'e 5 mission. —MARK ZASTROW

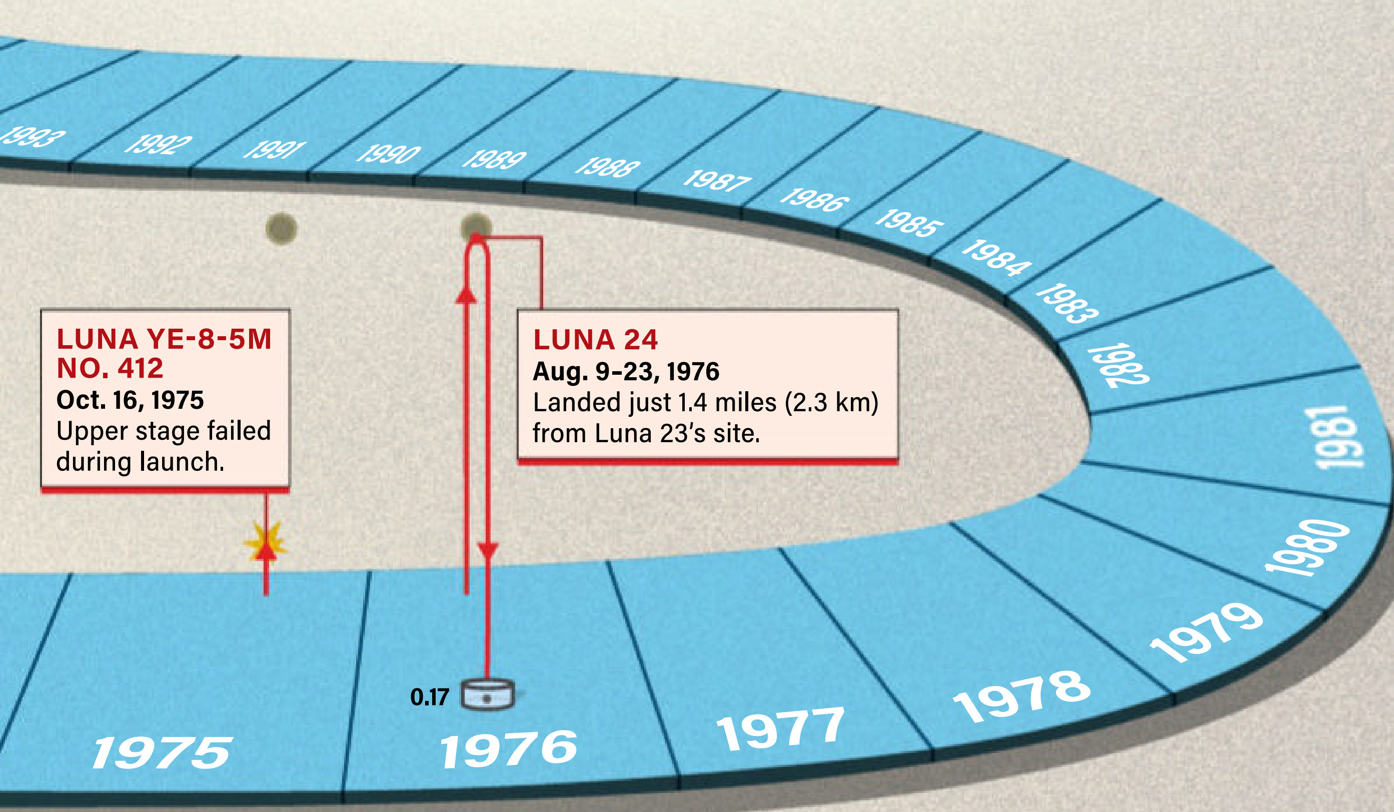


NASA/JPL-CALTECH/ASU/MSSS

Perseverance takes in the view

Mars' Jezero Crater has a new visitor capturing its stunning vistas. NASA's Perseverance rover took this panorama Feb. 21, 2021 — three days after it landed — using a pair of cameras mounted to its mast. About 1 mile (1.6 kilometers) in the distance sits the roughly 200-foot-tall (60 meters) ridgeline of an ancient delta, consisting of a mass of sediment deposited when a long-lost river flowed into Jezero Crater. Beyond that lies the crater rim itself, some 2,000 feet (600 m) high. The inset shows a rock with a unique overhanging shape, carved and eroded by the martian wind. – M.Z.





FUTURE MISSIONS

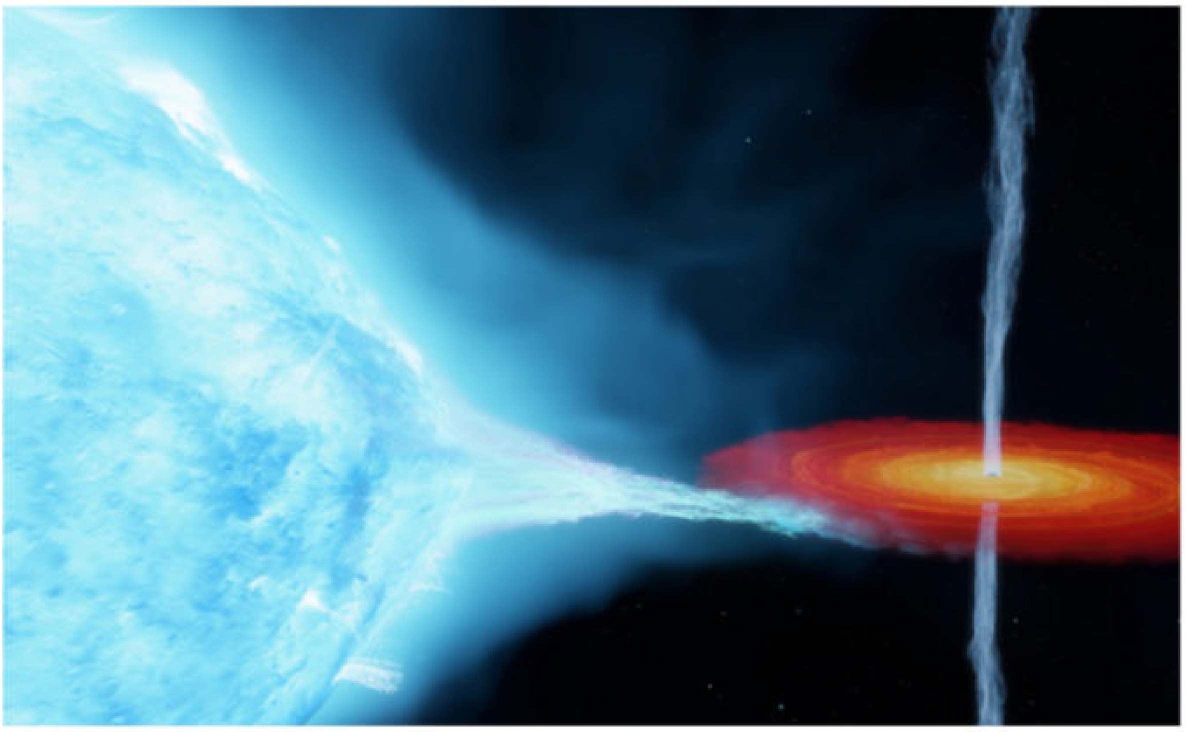
CHANG'E 6
2023
China's second lunar sample-return mission will use hardware similar to Chang'e 5.

MARTIAN MOONS EXPLORATION (MMX)
2024-2029
This planned Japanese mission to Phobos aims to collect at least 0.35 ounces (10 g) of material.

MARS SAMPLE RETURN
July 30, 2020–early 2030s
NASA and the European Space Agency are planning missions to retrieve the sample caches prepared by Perseverance. The agencies are targeting the early 2030s as a potential launch date.

ASTRONOMY: ROEN KELLY

Cygnus X-1 springs a massive surprise



PREMIER BLACK HOLE. Based on its updated distance, the Cygnus X-1 system lies 7,200 light-years away in the constellation Cygnus. INTERNATIONAL CENTRE FOR RADIO ASTRONOMY RESEARCH

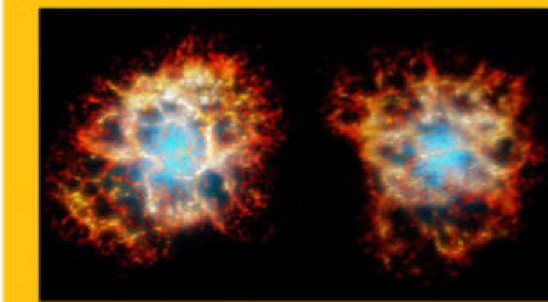
The first known black hole has a new mystery for physicists.

Cygnus X-1 was discovered in 1964 when a pair of rocket-borne Geiger counters picked up a strong source of X-rays coming from deep space. Astronomers traced the signal to a binary system located some 7,200 light-years away, consisting of a blue supergiant star — which could not be responsible for producing the X-rays — and another massive object. Eventually, astronomers agreed: The mystery object is a stellar-mass black hole, the remains of what was once a companion star that suffered an explosive — and implosive — death.

Astronomers also agreed that the system was 6,000 light-years away, making its black hole just under 16 times the mass of the Sun. But a study published Feb. 18 in *Science* has revealed the distance to Cygnus X-1 is actually about 7,200 light-years. So, to produce X-rays as bright as we see them, the black hole must be heavier than previously thought: 21 solar masses. This makes it the largest stellar-mass black hole ever discovered without the use of gravitational waves. It's so massive, in fact, that it challenges astronomers' understanding of how black holes form.

"Stars lose mass to their surrounding environment through stellar winds that blow away from their surface," said co-author Ilya Mandel of Monash University in a press release. "But to make a black hole this heavy, we need to dial down the amount of mass that bright stars lose during their lifetimes." This means it's possible stars can be more massive than originally believed when they go supernova.

A companion paper, published in *The Astrophysical Journal* the same day, revealed that Cygnus X-1's exceptional mass isn't its only record-breaking aspect. As lead author Xueshan Zhan explained, "Cygnus X-1 is spinning incredibly quickly — very close to the speed of light and faster than any other black hole found to date." According to the study, Cygnus X-1 may rotate at a slightly higher speed than previously deemed possible. If true, Cygnus X-1 would place new limits on how fast a black hole can spin. –C.B.



THOMAS MARTIN, DANNY MILISAVLJEVIC AND LAURENT DRISSEN

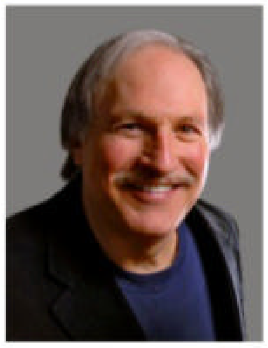
THE CRAB NEBULA'S DELICATE HEART

Although the Crab Nebula (M1) appears as a fuzzy patch of light through small scopes, larger instruments reveal a complex, twisting structure. And a stunning new 3D reconstruction of the remnant's central regions is taking our ability to study this millennia-old object to the next level. Researchers generated the model using the SITELLE imaging spectrometer on the 3.6-meter Canada-France-Hawaii Telescope on Mauna Kea, and published the work Jan. 18 in *Monthly Notices of the Royal Astronomical Society.* It shows the Crab in exquisite detail, highlighting the remnant's delicate lattice of gas filaments, which crisscross each other like a honeycomb. The 3D model allows astronomers to observe the Crab from every angle. The images shown here depict the Crab as seen from Earth (left), and a simulated rotated view of the nebula from another angle (right). Astronomers aren't sure what type of star produced M1, and the team's results don't quite match the type of supernova (and thus, progenitor star) that is most suspected. By getting up close to the Crab, scientists may now be better able to determine the kind of star that exploded to give birth to this amazing object. –A.K.

Unusual purchases

Looking for something to add to your observing collection?

Drawers and shelves with solar filters, octahedrite meteorites, spectroscopes, even a spinthariscope — the author's astro-toys may be typical of astronomers everywhere. BOB BERMAN



BY BOB BERMAN
Bob's newest book, Earth-Shattering *(Little, Brown and Company, 2019), explores the greatest cataclysms that have shaken the universe.*

We're into astronomy to be wowed and amazed. Sometimes this arrives at no cost or effort, as when a bolide tears across the sky. At other times, a glorious apparition might indeed be free, but can be improved with the right equipment, as when last year's great Comet C/2020 F3 (NEOWISE) was visible to the naked eye but wonderfully enhanced through binoculars.

Beyond bright comets, we can boost the naked-eye pleasure of solar totalities, the Milky Way, and large star clusters like the Pleiades with binoculars, which are thus essential instruments. We can safely watch solar eclipses with eclipse glasses, and telescope filters bring out details that boost our observing enjoyment. Today's theme: further astro-accessories that are super-cool or downright peculiar.

The typical stuff we buy is familiar to all. In the January 2020 issue ("Invitation to the dark side"), I mentioned that as a teenager I first explored the sky, like so many others, with a 60mm refractor, then later spent countless hours using a 6-inch f/8 reflector. Presently, you'll find me still observing deep-space wonders with the pier-mounted 12.5-inch f/6 equatorial-mounted reflector I bought 40 years ago. And I still gaze at solar system objects through my 5-inch 1997 Takahashi refractor — always with a binoviewer, since I'm hooked on the 3D sensation.

Housed in separate observatories, this equipment ought to suffice. Nonetheless, the astronomy passion provokes a peculiar blend of art and avarice. An ever-increasing number of science gadgets typically occupy the drawers and closets of backyard astronomers and physics teachers. Yet for reasons only a therapist could explain, I want you to buy more. Specifically, the ones I have. That's why I'll now give you sales pitches for my favorite half-dozen:

1. A swing-arm binocular mount: If you can't afford those fabulous pricey image-stabilized binoculars, attach your inexpensive model to a long swing-arm device — the kind with parallel metal bars. They keep you safely distant from the clunky tripod and remain pointed to the target even when you lower the swing arm to share the view.

2. A star spectroscope: You might have to hunt for one online. But the pure saturated colors emanating from stars — a dramatic break from the mere pastels seen through your telescope — will take your breath away. Observing the vivid Balmer lines in A-type stars like Vega or the swarthy, complex molecules seen in M-class supergiants blends revelatory physics with jaw-dropping beauty.

3. A spinthariscope: Go to United Nuclear's website (https://unitednuclear.com) and buy their best model; it's currently $50. Through it, you'll see atoms disintegrating. No joke — you'll view countless scintillating pinpoints as if you're carrying around your own globular cluster, albeit one that's out of focus.

4. A pocket spectroscope: Get one of the solid metal five-prism models in a wooden box (you can find them for under $150) and have fun observing streetlights or unscrambling the Sun's light. You think the sky is blue? With this device, you'll discover its true color. At dinnertime, you'll find butter solely emits green and red light. Endless revelations.

> **The astronomy passion provokes a peculiar blend of art and avarice.**

5. Meteorites: Keep one in your living room. Pass it around and let friends clutch an asteroid in their hand. I recommend octahedrites because they look like stereotypical meteorites, contain regmaglypts (small depressions that form as the meteorite streaks through Earth's atmosphere), and strongly pull on magnets.

6. A Gemini Sky Window: I still use this swiveling first-surface flat mirror with a metal binocular holder attached above it so you can comfortably observe the sky while looking downward, seated at a table, with no neck strain. It's just one example of the cool stuff that was manufactured 30 or 40 years ago that you might stumble across. I can't tell you what your Sky Window equivalent might be, but you'll know it when you see it.

Telescopes are merely the preliminary money sinks you encounter once you're betrothed to the muse who rules celestial profligacy. Carried off in her addictive caress, we learn the true origin of the phrase "the sky's the limit."

BROWSE THE "STRANGE UNIVERSE" ARCHIVE AT **www.Astronomy.com/Berman**

Asteroid dust found at Chicxulub Crater

COLD CASE SOLVED? An asteroid smashed into the Yucatán Peninsula 66 million years ago, wiping out the majority of life on Earth, including all non-avian dinosaurs. WILLGARD KRAUSE/PIXABAY

Some 66 million years ago, a city-sized asteroid barreled through Earth's atmosphere and slammed into the shallow waters off the Yucatán Peninsula in the Gulf of Mexico. The cosmic artillery strike gouged a 125-mile-wide (200 kilometers) crater in Earth's surface, lofting plumes of vaporized rock and debris into the air that globally blocked out the Sun for years or even decades. The reduced sunlight caused surface temperatures to plummet by as much as 50 degrees Fahrenheit (28 degrees Celsius), ushering in a period of mass extinction that killed 75 percent of life on Earth.

But eventually, the dust settled.

Fast-forward to the 1980s, and scientists uncovered traces of asteroid dust — mainly iridium, which is common in some types of asteroids yet rare in Earth's crust — scattered across the globe. They found the dust in the geological layer that corresponds to the time of the dinosaurs' extinction. Then, in the following decade, researchers discovered Chicxulub Crater in the Gulf of Mexico. Because the crater appeared to be the same age as the global rock layer enriched with asteroid dust, researchers were fairly certain they had figured out the cause of the dinosaurs' demise.

Now, a new study published Feb. 24 in *Science Advances* may have officially closed the case for good.

The latest evidence comes from rock core samples plucked from Chicxulub Crater itself, which is buried beneath the seafloor. In the most recent study based on samples collected by an international collaboration during a 2016 mission, researchers say they've found the first unambiguous evidence of asteroid dust from within Chicxulub.

The team found the highest concentration of iridium-peppered rock within a 2,600-foot-long (800 meters) core sample taken from the crater's peak ring. This sample likewise shows elevated levels of other elements commonly associated with asteroids, giving it a chemical fingerprint that strongly resembles that of the asteroid dust found around the globe in the 1980s. As study lead Steven Goderis said in a press release, "the circle is now finally complete." — J.P.

1.3 million

The number of binary star systems detected by the Gaia space telescope within about 3,000 light-years of Earth — 6,500 times the number cataloged by its predecessor mission, Hipparcos.

"Super Soaker" rocket seeds cloud at edge of space

NASA'S WALLOPS FLIGHT FACILITY/POKER FLAT RESEARCH RANGE/ZAYN ROOHI

On Jan. 26, 2018, a trio of NASA sounding rockets launched from Fairbanks, Alaska, on a mission to create an artificial night-shining, or noctilucent, cloud. Also known as polar mesospheric clouds (PMCs), these specters are wisps of ice crystals that form roughly 50 miles (80 kilometers) high and glimmer after twilight, illuminated by a Sun that has already set. This long-exposure photograph shows the path of the main rocket, dubbed the "Super Soaker," which deployed an explosive canister containing about 485 pounds (220 kilograms) of water at an altitude of about 53 miles (85 km). Also visible are the trails of two support rockets, which fired vapor tracers — streams of trimethyl aluminum gas that react with oxygen in the atmosphere and luminesce — to track wind movement. The research was intended to investigate why PMCs are so often caused by water exhaust from rocket launches. The results, published Feb. 1 in the *Journal of Geophysical Research: Space Physics,* indicate that water exhaust not only provides material for the icy clouds, but its explosive injection into the air also cools the immediate surroundings by roughly 45 degrees Fahrenheit (25 degrees Celsius). These conditions are ripe for forming a PMC. — M.Z.

Seeing the Great Conjunction

Jupiter and Saturn put on a show with a variety of visual appearances.

This cropped and enhanced 50mm (effective focal length 70mm) image of the Great Conjunction on Dec. 21, 2020, was taken at 17:28 UT at closest approach, when the worlds were 6' apart. The view, from Maun, Botswana, occurred 24 minutes after sunset, which reduced the ill effects of glare. Unfortunately, only Jupiter was bright enough to be seen with the naked eye, and thickening cirrus clouds soon occulted them. STEPHEN JAMES O'MEARA

BY STEPHEN JAMES O'MEARA
Stephen is a globe-trotting observer who is always looking for the next great celestial event.

It's rare that we have a chance to see a naked-eye planetary phenomenon with little precedent in recorded human history. Yet, last year, those fortunate enough to have clear skies on Dec. 21 had a chance to witness something not seen in the night sky since 1226: a Great Conjunction between Jupiter and Saturn that brought the planets within 6' of one another.

What people saw — or didn't see — this time around might surprise you.

Incomparable beauty

The big question on many minds was whether the two planets would defy the resolving power of the naked eye and appear as a single (or elongated) star — especially when Jupiter, shining at magnitude –2.0, outshone Saturn (0.6) by about 12 times. No close pairing of comparable brightness exists among the naked-eye stars, though other planetary conjunctions have come close: In 2015, Venus and Jupiter approached within 18' of one another. Glare from the planets made their separation appear smaller when seen against a dark sky, though not enough to visually merge into one.

Glare is a problem familiar to double-star observers. Mizar and Alcor — a 2nd-magnitude primary and a 4th-magnitude secondary seen 11.8' apart — have long been considered a test for naked-eye visual acuity. In fact, studies have shown that they are almost exactly at the predicted threshold of distinguishability for those with 20/20 vision. The Jupiter and Saturn conjunction presented a much greater challenge: The glare from Jupiter is much stronger than Mizar's, and the gap between Saturn and Jupiter was just half of the separation between Alcor and Mizar.

One "star" or two?

So, what did people see? From a small sample of observations that I collected from acquaintances — all made during closest approach — the results depended on both atmospheric and physiological factors.

Several casual observers from Maun, Botswana, reported that the two planets appeared as a single star. All of them saw the event during nightfall, when glare is most prominent. The planets had just emerged from beneath a cloud bank and were only about 5° degrees above the horizon, where atmospheric extinction is great. They were not disappointed, though, as they said the single star aspect was what they were "expecting to see."

This telephoto image from Nov. 4, 2020, was intentionally placed out of focus to show the color difference between Saturn (top) and Jupiter (bottom). STEPHEN JAMES O'MEARA

Edgar Castro of the Universidad Galileo in Guatemala City had a similar experience when observing about 15 minutes before the start of astronomical twilight. "All I wanted to see," he said, "was if indeed the two bright spots would become one and, indeed, they did. At first glance it looked like a single point of light. I had never seen that before and it was wonderful."

Also observing during nautical twilight, longtime amateur observer Leo Cavagnaro, in Mendoza, Argentina, had to climb his roof to view the planets, which were about 10° above the horizon. "Both planets, at least for me and my now older eyes, were easy to discern," he reported. "I'm amazed at how close to each other they were when viewed with the unaided eye." He also remarked on how "beautiful the color combination was," with "yellowish Saturn" so close to "white Jupiter."

Terry Atwood of Louisiana's Shreveport-Bossier Astronomical Society also commented on color. "As soon as they were visible in the fading twilight," he said, "they first looked like two colorless points of light, reminiscent of two distant high-altitude balloons reflecting sunlight. As the sky darkened, brilliant Jupiter took on a pale pink coloration while Saturn became a distinct yellow next to our neighbor's spreading magnolia tree." He adds that while he and his sister-in-law could discern both planets "as two separate points of light," without optical aid, his wife Ruth could see only one.

Veteran planetary observer and "newly minted octogenarian" Klaus Brasch of Flagstaff, Arizona, said he had no difficulty splitting the pair. "Although I wear trifocal glasses and still have pretty good eyesight, I was pleasantly surprised to readily resolve both points of light without difficulty."

As Atwood watched the sight, he wondered if we were viewing something akin to the Star of Bethlehem. "Because it took so many months for the two planets to meet in the evening twilight," he said, "we wondered if anyone else would have noticed without the announcements from the TV weathermen." Atwood notes that according to the Gospel of Matthew's account, only the Wise Men — astronomers well-acquainted with the stars — noticed it. Who else would have taken note?

As always, share your thoughts and observations at sjomeara31@gmail.com.

BROWSE THE "SECRET SKY" ARCHIVE AT **www.Astronomy.com/OMeara**

EARTH IS A P

As researchers strive to understand our solar system, there's a perfect laboratory right under our feet.

BY ALISON KLESMAN

Researchers simulating a manned Mars mission practice collecting geologic samples in Hawaii, where some landscape features are similar to regions of Mars. Training on Earth allows future astronauts to learn how to best achieve their goals before setting foot on another world. NASA

IN 2017, NASA CELEBRATED 20 consecutive years of Mars exploration — the longest humankind has continuously monitored another planet. But there's a key phrase in that statement that's easy to overlook: *another* planet. Even as planetary scientists strive to understand the fellow planets circling our Sun, it's worth remembering that we have the perfect scientific testbed right at our fingertips.

As the most familiar planet — and perhaps the strangest — Earth gives us insight into the forces that shaped our solar system, revealing clues about how rocky planets form and evolve. Studying Earth lets us walk before we run, testing techniques and technologies in a familiar setting before sending them to other worlds.

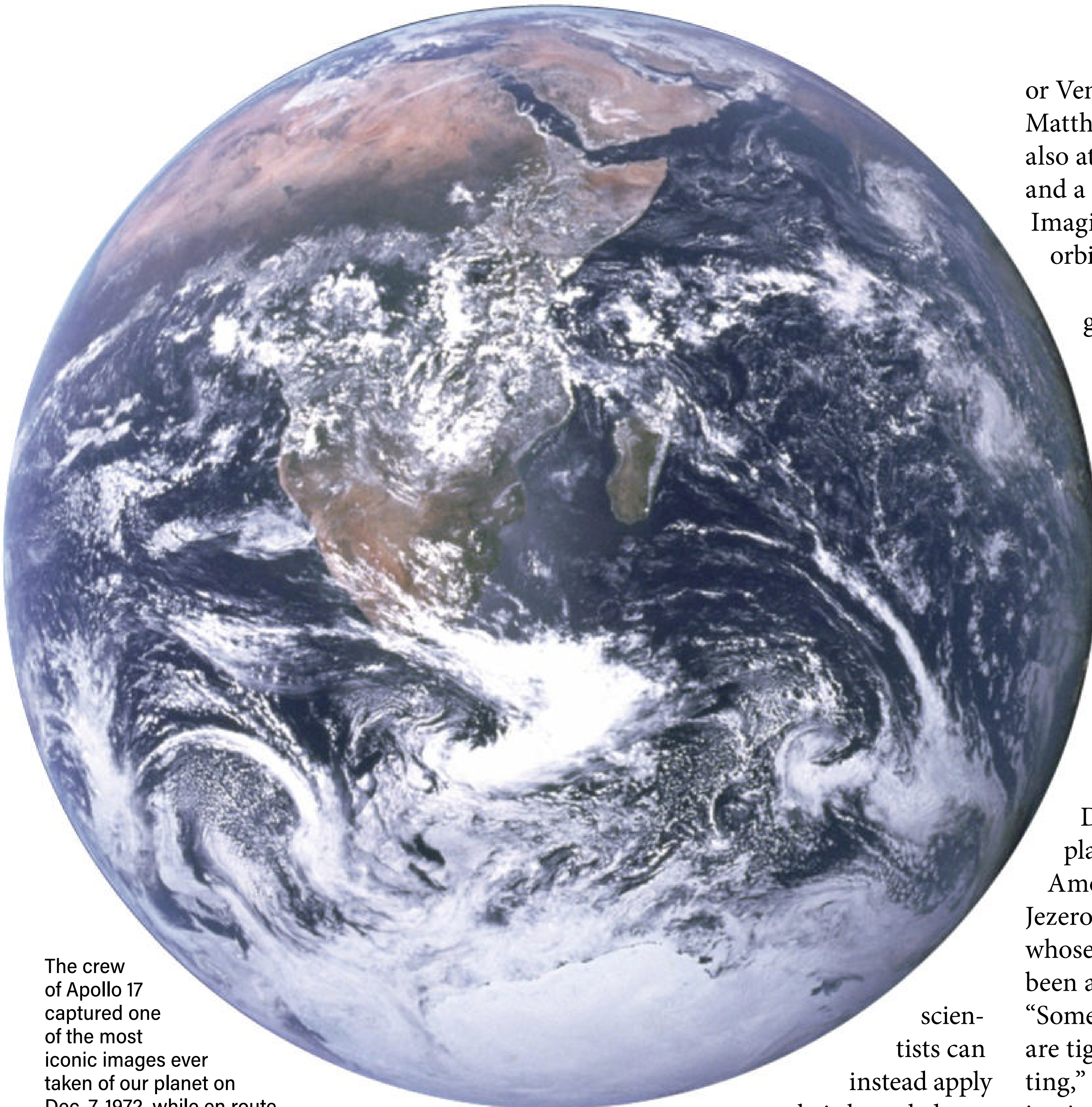
But the more we learn, the more we see that our planet is one of the weirdest places we've ever encountered, uniquely shaped and forever altered by the life-forms it sustains.

Comparative planetology

Every planet in our solar system formed from the same ingredients: gas and dust in the solar nebula around our nascent Sun. The inner planets assembled closer to our star, where temperatures were warmer, meaning volatiles — elements that turn into a gas at low temperatures — were rare. As a result, these planets are largely rocky, with atmospheres and surface water that came much later, released through geologic processes or delivered by impacts.

Although their sizes, compositions, and distances from the Sun differ, the basic processes

LANET TOO!



The crew of Apollo 17 captured one of the most iconic images ever taken of our planet on Dec. 7, 1972, while en route to the Moon. NASA

that formed and shaped Mercury, Venus, Earth, and Mars can be read in the rocks right under our feet. "The same physics apply on all the planets," says Rebecca Ghent, a senior scientist at the Planetary Science Institute whose current work focuses on the geology of Earth, the Moon, and Mars. It's the ways in which those physics play out, she says, as well as which ingredients are available on each planet, that create the differences that provide vital clues about planetary evolution.

All the terrestrial planets, she says, are subject to gravity-driven effects such as cratering, sedimentation, and landslides; interior-driven processes such as volcanism; and processes driven by water on or below the surface. Taken together, "comparative studies of the planets can tell us lots more about the underlying processes than we can learn from studying a single planet in isolation," Ghent says.

Essentially, instead of starting from scratch to understand a given world, scientists can instead apply their knowledge of how processes work on one planet (say, Earth) to extrapolate how they work somewhere else. This is called comparative planetology, and it's a valuable first step when looking out across the solar system.

"Terrestrial analogues and how we can study specific locations on Earth and apply that knowledge to places that seem completely unterrestrial, like [Saturn's moon] Titan or certain places like Mars or Venus, are all really important," says Matthew Chojnacki, a research scientist also at the Planetary Science Institute and a participant in the High Resolution Imaging Science Experiment, or HiRISE, orbiting Mars.

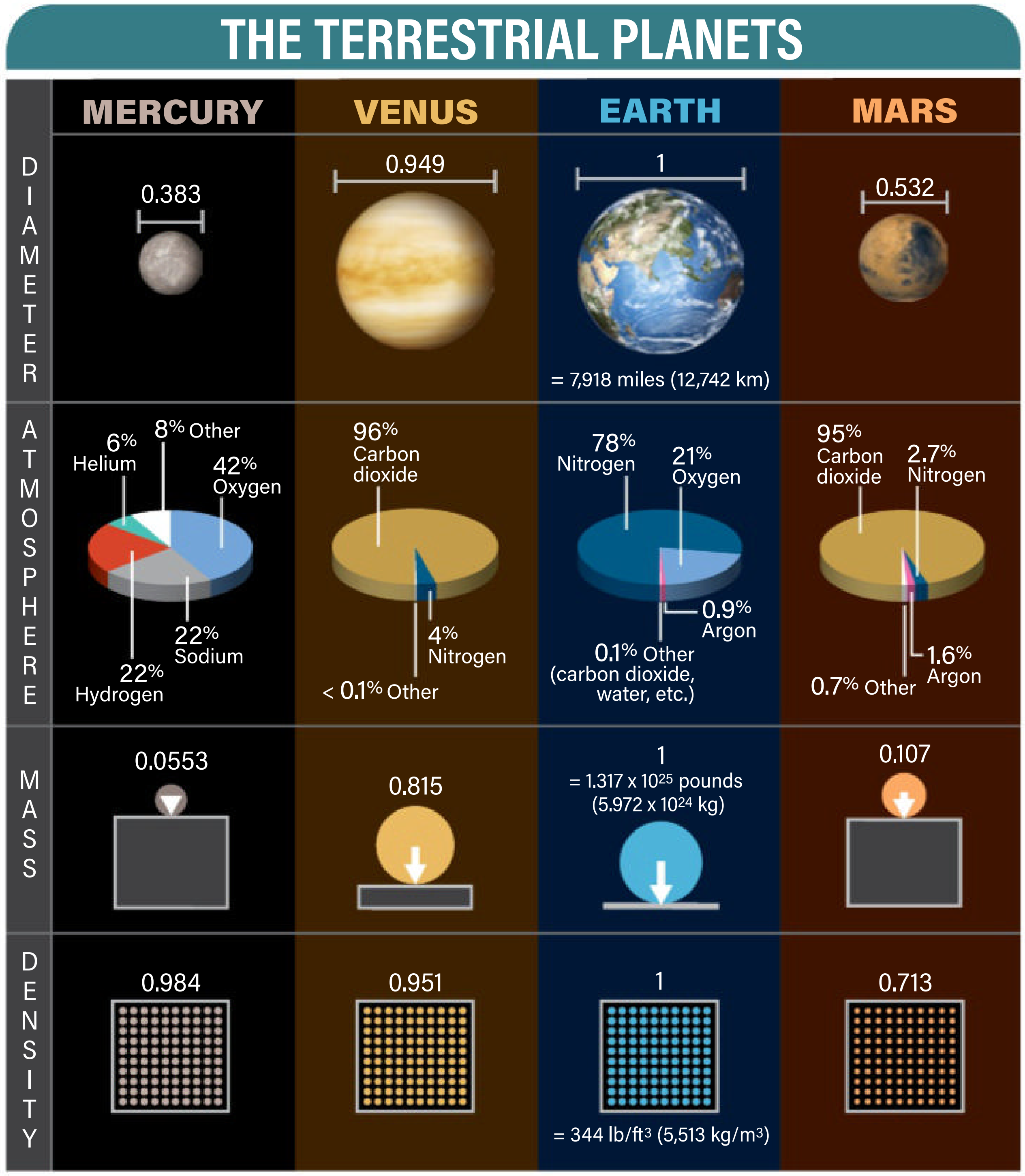
Sometimes, processes are no longer active but have left signs of their presence, Ghent says. Based on how the presence of water has changed Earth's landscape over time, scientists have identified widespread evidence of flowing surface water on Mars in the planet's past.

One such place is the river delta preserved inside Jezero Crater, where NASA's Perseverance rover touched down in February. John Mustard of Brown University chairs the Mars 2020 mission's Science Definition Team and is one of many planetary scientists studying the site. Among other features of interest, Jezero contains the mineral magnesite, whose formation suggests the region has been altered by water. Furthermore, "Some magnesite deposits on the Earth are tightly coupled to a biological setting," Mustard says, making Jezero an intriguing location to search for signs of ancient life — one of the rover's four main science objectives.

Meanwhile, Perseverance's predecessor, Curiosity, has shown researchers that Gale Crater, an ancient lakebed, once experienced conditions akin to modern-day Iceland. To make the find, published Jan. 18 in *JGR Planets*, researchers compared soil formed in various locations on Earth to the readings sent back from the rover. "Earth

NASA's fleet of airborne observatories includes a DC-8 aircraft (left) modified to carry a slew of instruments that can be swapped out for each new mission. The agency also operates the ER-2 (right) — a modified U2 spy plane capable of reaching altitudes up to 70,000 feet (21,000 m). FROM LEFT: NASA PHOTO/JIM ROSS; NASA/CARLA THOMAS

Its vantage point at L1 afforded the DSCOVR spacecraft an excellent view of the Aug. 21, 2017, total solar eclipse as it crossed North America. DSCOVR snaps pictures of Earth every two hours, providing researchers with a rich dataset that can't be obtained from low Earth orbit. NASA EPIC TEAM



The solar system's terrestrial planets formed close to our star out of roughly the same ingredients. Many differences today arise because of slightly different initial conditions, although general comparisons can still be made. Here's how the four terrestrial planets stack up; note that the mass, diameter, and density of Mercury, Venus, and Mars are all shown as ratios of Earth's values. *ASTRONOMY*: ROEN KELLY

provided an excellent laboratory for us in this study," said co-author Kirsten Siebach of Rice University in a press release announcing the discovery. "The range of climates on Earth allowed us to calibrate our thermometer for measuring the temperature on ancient Mars."

Something in the air

Geology isn't the only feature researchers can compare between planets. On Earth, weather prediction and climate modeling have become integral to our daily lives. Over the past several decades, meteorologists have developed sophisticated models based on advanced observations of how our atmosphere works.

While Earth's atmosphere certainly contains a different mix of ingredients than its neighbors, both near and far, the underlying physics that govern how an atmosphere acts remain the same. "Climate models that have been created for the Earth are now increasingly being adapted to look at other planets: Mars, even the gas giants, and exoplanets," says Richard Eckman, program manager for NASA's Atmospheric Modeling and Analysis Program.

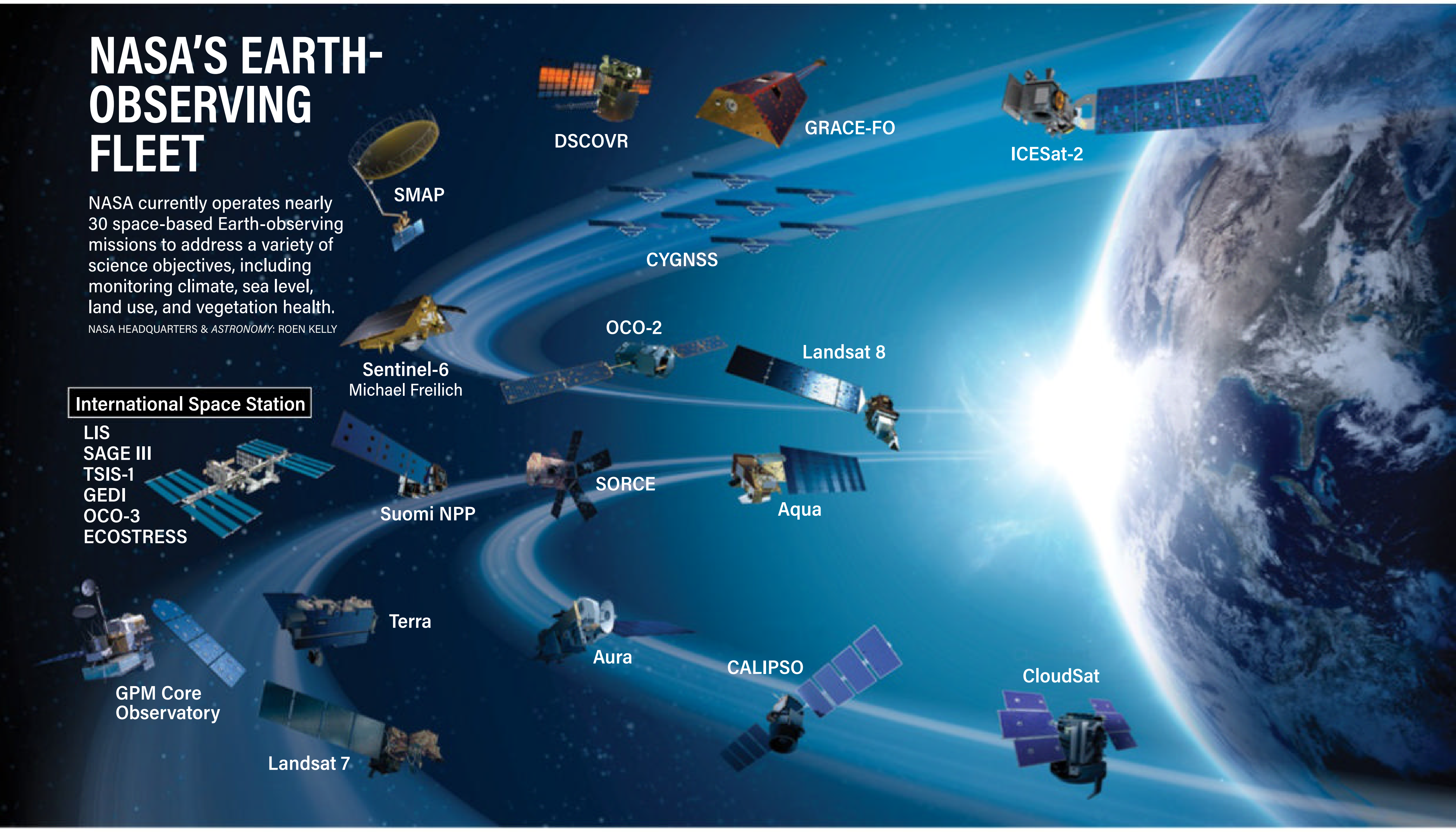
Eckman also serves as the earth science representative to the cross-divisional exoplanets science program at NASA. This group, he says, seeks to better understand exoplanets by exploiting the similarities between observing our planet and, as technology progresses, observing planets around other stars. "We are able to test the models on Earth, and we have some confidence in [the] physics and parameterizations and so forth," he says. "Obviously, for the gas giants and these other very different kinds of atmospheres, I think that there's a lot of adaptation that's done. But for terrestrial-like planets, certainly Mars and terrestrial exoplanets, the modifications are more straightforward."

So close, yet so far

Despite the many benefits of using Earth as a laboratory, the comparison eventually breaks down. "Venus, Earth, and Mars are on a continuum, where you have major changes in temperature, you have major changes in atmospheric pressure and atmospheric composition, and those bring some serious challenges to not just operating in those environments, but also in comparing the different geologic processes that are occurring there, because they're not exact," Chojnacki says.

For example, Mars today experiences a carbon dioxide cycle, while Earth supports a water cycle. But because water and carbon dioxide behave differently — especially under martian and terrestrial conditions — the two cycles are similar but not directly comparable.

Similarly, while martian winds sculpt the landscape just as terrestrial winds do, Mars' atmosphere is much thinner and its winds subsequently much weaker. "You don't see sand dunes migrating [on Mars] like they do in Egypt, for example," Chojnacki says. On Mars, "you have to wait a decade to see the kinds of



NASA'S EARTH-OBSERVING FLEET

NASA currently operates nearly 30 space-based Earth-observing missions to address a variety of science objectives, including monitoring climate, sea level, land use, and vegetation health. NASA HEADQUARTERS & *ASTRONOMY*: ROEN KELLY

changes that you might see in the African sand seas in just a month. There is a more muted effect because of the differences in atmosphere."

"As we study comparative planetology, you think, 'Let's study these terrestrial planets, the rocky ones. They all should follow the same [evolutionary] path.' And they don't," Mustard says. "There's this stochasticity, this randomness that comes into play. And I think that's a fascinating part of it. Earth is fantastic, we really know how it operates, but we can't be naïve enough to think that every planet operates that way."

Earth science

NASA's Earth Science Division seeks to understand our planet as a unique environment in its own right. "Studying the Earth from space has always been an important part of NASA's mandate," says Hank Margolis, program manager for NASA's Terrestrial Ecology Program. "NASA and other space agencies have a large fleet of satellites that make observations of the Earth's surface and its atmosphere."

Earth science research currently receives about $1.9 billion from NASA's budget each year — on par with the amount awarded to the agency's astrophysics division, which studies the larger universe as a whole. As of early 2021, NASA operates around 30 space-based Earth-observing missions, including joint missions with other agencies. By comparison, NASA has about half that many interplanetary missions scattered throughout the solar system.

And Earth scientists have more than satellites at their disposal. Airborne missions provide measurements close to the ground that are difficult or impossible to make from low Earth orbit, Eckman explains. These missions target a variety of areas, ranging from air quality and cloud formation to the amount of ice, coral, or vegetation on land or sea. Many airborne missions also provide a cost-effective way to test technologies ultimately bound for space, whether aboard Earth-orbiting satellites or a spacecraft destined for another world.

> Earth science research currently receives about $1.9 billion from NASA's budget each year.

Cameras and other passive sensors record the amount of energy, such as reflected sunlight, coming from the planet. For Earth, Margolis says, that information can be related to "the biophysical properties of the land surface, such as the amount of leaves, the absorption of radiation by vegetation canopies, the types and the changes of land cover, the area of snow cover."

Active sensors send out signals, such as radio waves (radar) or laser light (lidar), which bounce off land and water, reflecting back to the spacecraft. Scientists can then determine how the signal has changed and relate those changes to properties of the planet below. The most recent addition to the Earth-observing fleet, Sentinel-6 Michael Freilich, uses radar to measure sea level of more than 90 percent of Earth's oceans to within just a fraction of an inch. Lidar allows

Decades of observations have revealed that the surface of Mars was much wetter in the past. The Perseverance Mars rover's landing site in Jezero Crater (left) shows the telltale features of an ancient river delta. For comparison, at right is the Mississippi Delta, photographed by NASA's Landsat 7 in 2001. ESA/DLR/FU-BERLIN; NASA IMAGE CREATED BY JESSE ALLEN, USING DATA PROVIDED BY THE UNIVERSITY OF MARYLAND'S GLOBAL LAND COVER FACILITY

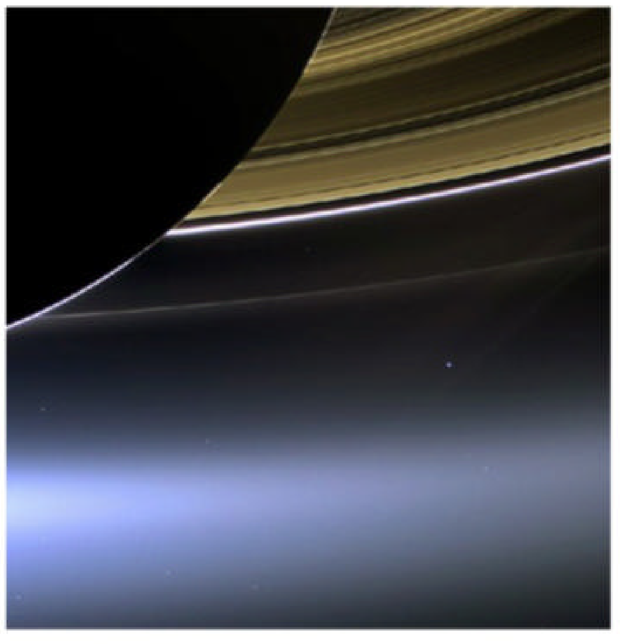
researchers to visualize the vertical structure of vegetation, while radar can characterize vegetation even through cloud cover, Margolis says. Studying all these aspects of Earth allows researchers to understand how our planet is evolving and predict how land, water, and vegetation might change in the future.

A unique perspective

Naturally, most Earth-observing satellites orbit Earth, with many in geostationary orbits that keep them above one region of the planet even as it rotates. But one mission is different: Launched in 2015, the Deep Space Climate Observatory (DSCOVR) was originally proposed in the late '90s by then-Vice President Al Gore. But the spacecraft was put on hold for decades until the Obama administration resurrected it as a joint heliophysics and earth science mission, says Eckman.

Now operated by NASA, the U.S. Air Force, and the National Oceanic and Atmospheric Administration, DSCOVR is located roughly 1 million miles (1.5 million kilometers) from Earth, positioned between our planet and the Sun at a stable Lagrange point where the gravitational influences of our planet and our star cancel each other out. From this vantage point, called L1, the mission studies the solar wind in real time, offering warnings as much as 60 minutes before solar storms hit our planet. But DSCOVR also looks back at Earth, snapping photos every two hours at 10 different wavelengths that include ultraviolet and infrared light (those images are available daily to the public at https://epic.gsfc.nasa.gov/).

"But it's way more than pretty pictures," Eckman says of DSCOVR's earth science contributions. "Amazingly, from a million kilometers out, we can measure ozone and aerosols and clouds and sulfuric acid droplets from volcanic eruptions and all kinds of cool stuff, useful stuff — and looking uniquely at the entire Earth in a way that even geosynchronous weather satellites can't."

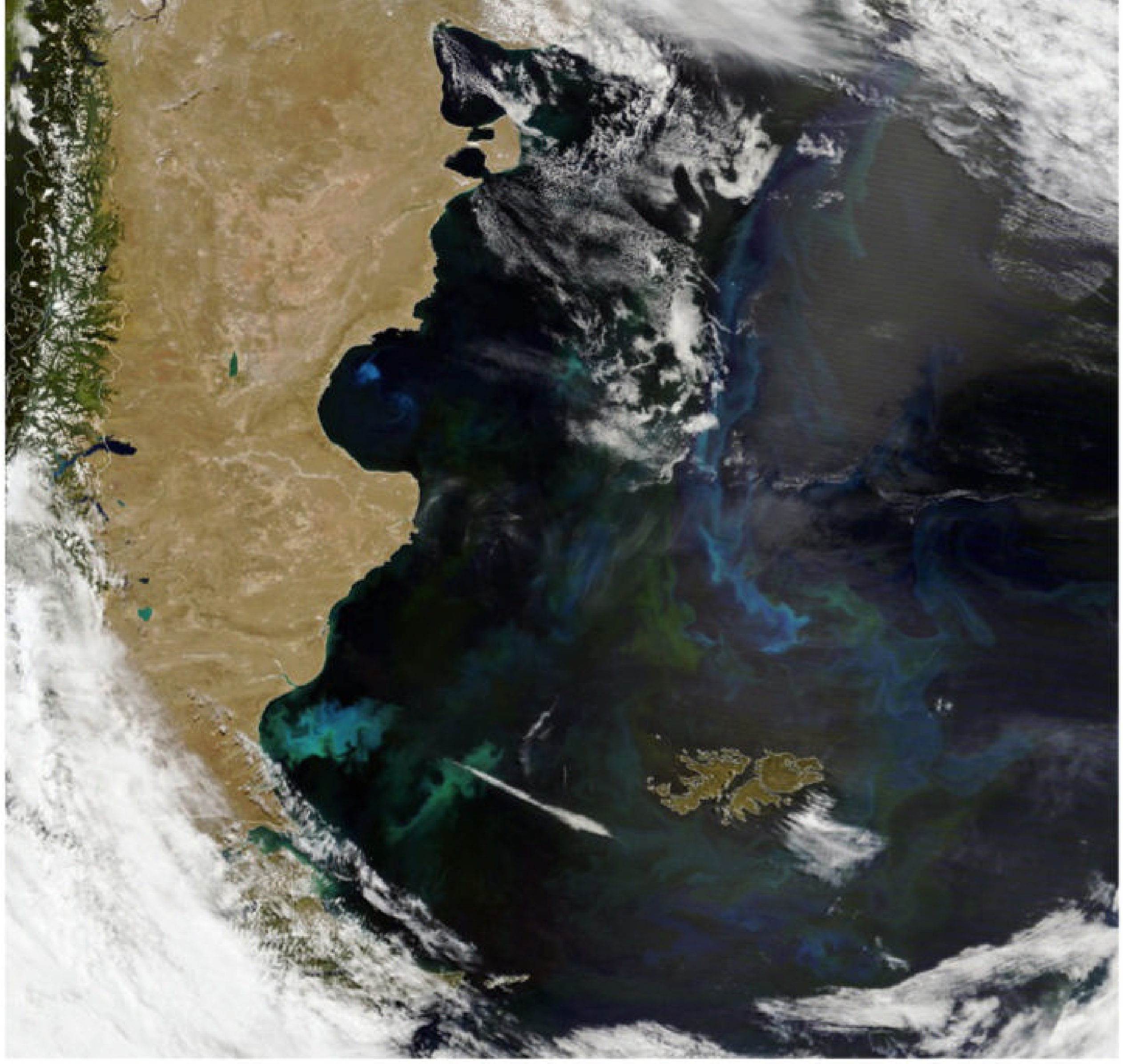


In July 2013, the Cassini spacecraft captured this image of Earth (the bright point beneath the rings) as it appears from Saturn. Images such as this help put our planet in context as one of many worlds in the solar system. NASA/JPL-CALTECH/SPACE SCIENCE INSTITUTE

Even at its vast distance, DSCOVR's camera can resolve areas as small as about 16 miles (25 km) across. And because it regularly takes global pictures, Eckman says, DSCOVR can look at certain aspects of vegetation — like the size of plant canopies or the amount of biomass present — more easily than satellites closer to the planet. Plus, DSCOVR's pictures show diurnal, or daily, variations across the planet that can't be observed from low Earth orbit. "DSCOVR has made the case of being a highly productive science instrument apart from the daily RGB [true-color] visible images that are probably what most people think about," Eckman says.

The strangest planet?

Such long-term observing campaigns of Earth have taught scientists one sure thing: Our planet is unique and bizarre, with unusual properties that *don't* match those of any other world we've



Phytoplankton are microscopic plantlike organisms with a macroscopic role to play on Earth: They turn carbon dioxide into oxygen through the process of photosynthesis. This image, taken by NASA's Terra satellite, shows the Argentine Sea and the Falkland Islands off the coast of Argentina. The colorful swirls just offshore at lower left signal a massive bloom of phytoplankton that measures more than 62 miles (100 km) across. LAUREN DAUPHIN, USING LANDSAT DATA FROM THE U.S. GEOLOGICAL SURVEY AND USING MODIS DATA FROM NASA EOSDIS LANCE AND GIBS/WORLDVIEW

seen, either in our own solar system or beyond it.

Earth is the only planet with abundant liquid water driving an active water cycle. From weather to weathering, the effects of water are everywhere. Our home world is also the only known planet with active plate tectonics, in which distinct pieces of crust are constantly created and destroyed in a planetwide recycling program that drives phenomena like earthquakes and volcanoes. Tectonic activity is even responsible for releasing volatiles from Earth's interior, which helped create — and now maintain — our atmosphere.

Then there's the Moon. "Without the catastrophic Moon-forming impact very early in the solar system's history, the Earth would not be the way it is today, at all," Mustard says. That impact and the satellite it formed have affected everything from the strength of Earth's tides to the stability of our planet's 23.4° tilt. Without the Moon, our tides would be solely influenced by the Sun — and, given its vast distance, would consequently be much weaker. This would have brought about very different landscapes at the interface where water meets land. And with no Moon, our planet's rotation axis would wobble unpredictably, destabilizing the climate on timescales of just a few thousand years.

Perhaps in part because of all these factors, Earth is, thus far, the only planet we know of that hosts life. And that life has left its mark on our world. "Over geologic time periods, the Earth's vegetation has played a major role in the evolution of the atmosphere," Margolis says. In fact, "vegetation is largely responsible for the current level of oxygen in the atmosphere: 20 percent."

Earth is the only planet with abundant liquid water driving an active water cycle.

Earth started out with an atmosphere rich in methane and carbon dioxide. But photosynthesis, the process by which plants convert sunlight and carbon dioxide into energy, releases oxygen as a byproduct. "There was life in existence as photosynthesis was getting going," Mustard says. "But then, 2.5 billion years ago, Earth pivoted to an oxygen [atmosphere] and it just killed off [nearly] all the early forms of life. It was just a catastrophic moment for life at that time." But that catastrophic moment paved the way for life — and Earth — as we know it today.

Yet another curious characteristic of our planet: Earth has a huge number of minerals. Referencing work led by Robert Hazen of the Carnegie Institution for Science, Mustard explains that meteorites — leftover planetary building blocks — have a small number of minerals. "Then on the Moon, you've got an increasing number." Finally, he says, "You go to the Earth and it's just ridiculous."

Why is this? The prevalence of water isn't enough to explain the disparity, Mustard says. But "if you look at Earth's history, the number of minerals that we know exist increases with time," he explains. "You had these big explosions of mineral diversity something like 600 million years ago — which coincides with the emergence of life on land. [Life] just changes the chemical reactions, the environment, so much. … The coevolution of life and geology on Earth — we can't disentangle that, I don't think."

But perhaps the clearest example of life shaping Earth's land, sea, and air is much more recent — and, in fact, currently playing out. "I'd say humans are among the dominant forces of change on the planet," Mustard says. Much of his career has been dedicated to observing how Earth's surface changes in response to both natural and human forces. And there are plenty of human forces at work. We remove or replace vegetation. We exhaust or reroute water supplies. We populate and reshape coastlines. And we produce or release massive amounts of atmosphere-altering gases. Many of these effects can be observed with relatively coarse data and commercially available software, Chojnacki says.

Fortunately, earth science is different from other planetary science in one final, fundamentally important way: Earth science is actionable science. By monitoring the changes our host planet undergoes, we can make choices and take actions that reduce or alter our effect on the landscape.

The signs of natural settling, human-built levees and canals, and global sea-level rise are all imprinted upon Louisiana's Barataria Bay, which appears here on Aug. 31, 1985 (left), and Oct. 2, 2020. As a result of both natural and human-induced change, the region has lost as much as 430 square miles (1,120 square km) of land in less than 100 years. LAUREN DAUPHIN, USING LANDSAT DATA FROM THE U.S. GEOLOGICAL SURVEY

"What we learn from spaceborne measurements can have very practical applications to human society — e.g., wildfire management, forest management, disaster management, improving agriculture, managing air pollution, managing biodiversity, etc.," Margolis says. And Chojnacki notes that the same remote-sensing techniques researchers use to determine how humans are affecting the planet can also show us how well mitigation efforts are progressing.

Beyond Earth

Despite its strangeness, Earth is the planet we are most familiar with and are best suited to survive on. Thus, it serves as a necessary jumping-off point when humanity turns its gaze outward. NASA once trained the Apollo astronauts to become lunar field geologists by taking them to Hawaii or Arizona. And researchers today are setting up simulated Mars camps in Utah and Hawaii or traveling to Antarctica to test how easy — or hard — it will be to carry out geologic research with rovers and in space suits. "It's useful to be on Earth and actually have a timeline and try to understand how you're going to collect that many geologic samples in eight hours with your supplies when you're in the field — and how complicated that gets in reality," says Chojnacki. "Field studies and terrestrial applications are certainly going to pave the way for lunar and martian exploration."

And as Eckman points out, several exoplanets have been identified in recent years with at least some Earth-like characteristics. Based on our understanding of the solar system, terrestrial planets, at their core, all likely share at least a somewhat similar origin story.

But, Mustard says, "Planets are built by chance. And we should be grateful and thankful that the chances that came together that formed the Earth resulted in this. It just says it's a special place and let's not mess it up."

EARTH AND VENUS: SEPARATED AT BIRTH

Venus and Earth are stunningly similar; in fact, Venus is often called Earth's sister planet. At first glance, it's easy to see why: Earth is a mere 1.1 times wider and 1.2 times more massive than Venus, and they're made up of largely the same material in equal amounts.

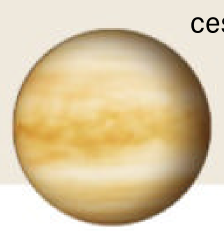
Yet, the two look vastly different. It's an experiment in how small initial differences can snowball into huge effects further down the line, leading one planet to become the lush, water-filled paradise we enjoy today, while the other becomes a broiling, toxic wasteland. But research suggests both may have started out with roughly the same amount of water. So, what happened? That's the million-dollar question.

We do know that Venus rotates retrograde, or backward, compared to its orbital motion around the Sun — the only planet to do so. Although its core is still hot, like Earth's, Venus has no plate tectonics. Its oppressively thick atmosphere is about 96 percent carbon dioxide, 4 percent nitrogen, and less than 0.1 percent other gases. Earth has a comparatively light atmosphere consisting of 78 percent nitrogen, 21 percent oxygen, and 1 percent other gases.

Despite these differences, Earth's strange sister still has much to offer. Venus doesn't look much like *modern-day* Earth, but scientists think the two were much more similar shortly after formation, potentially making Venus a good analogue for a younger Earth.

"Venus is the only planet that can teach us both about early Earth and the birth of both plate tectonics and continents — two processes that have profoundly shaped life on Earth," says Suzanne Smrekar, principal investigator of the Venus Emissivity, Radio Science, InSAR, Topography & Spectroscopy (VERITAS) mission, which is currently under consideration for NASA funding. Smrekar also worked on the Magellan spacecraft that orbited Venus in the early 1990s.

"On Earth, plate tectonics is the fundamental process that links the interior heat engine to surface geology and releases (and recycles) volatiles from the interior to create the atmosphere," Smrekar says. "Yet this process began billions of years ago, leaving only vague clues about how it started. There are many models but little data. By going to Venus … we have a chance to see processes that shaped the birth of our home planet in action!" *— A.K.*



ASTRONOMY: ROEN KELLY

Alison Klesman *is senior associate editor of* Astronomy. *Her academic introduction to astronomy was through planetary science, which still holds a special place in her heart.*

THE AGE OF multi-messenger astronomy

Cosmic rays, neutrinos, photons, and gravitational waves: Each of these signals carries a message. What can they tell us? BY ARWEN RIMMER

The IceCube Laboratory building at the South Pole stands atop an ice field laced with over 5,000 optical sensors. Computers in the lab building perform an initial round of processing before transmitting the data via satellite to researchers at the University of Wisconsin-Madison.
MARTIN WOLF, ICECUBE/NSF

For centuries, astronomers studying the stars were limited to information from visible light. Telescopes, photographic plates, and digital detectors were all developed to collect, magnify, and capture that signal.

But visible light isn't the only message the cosmos is sending us.

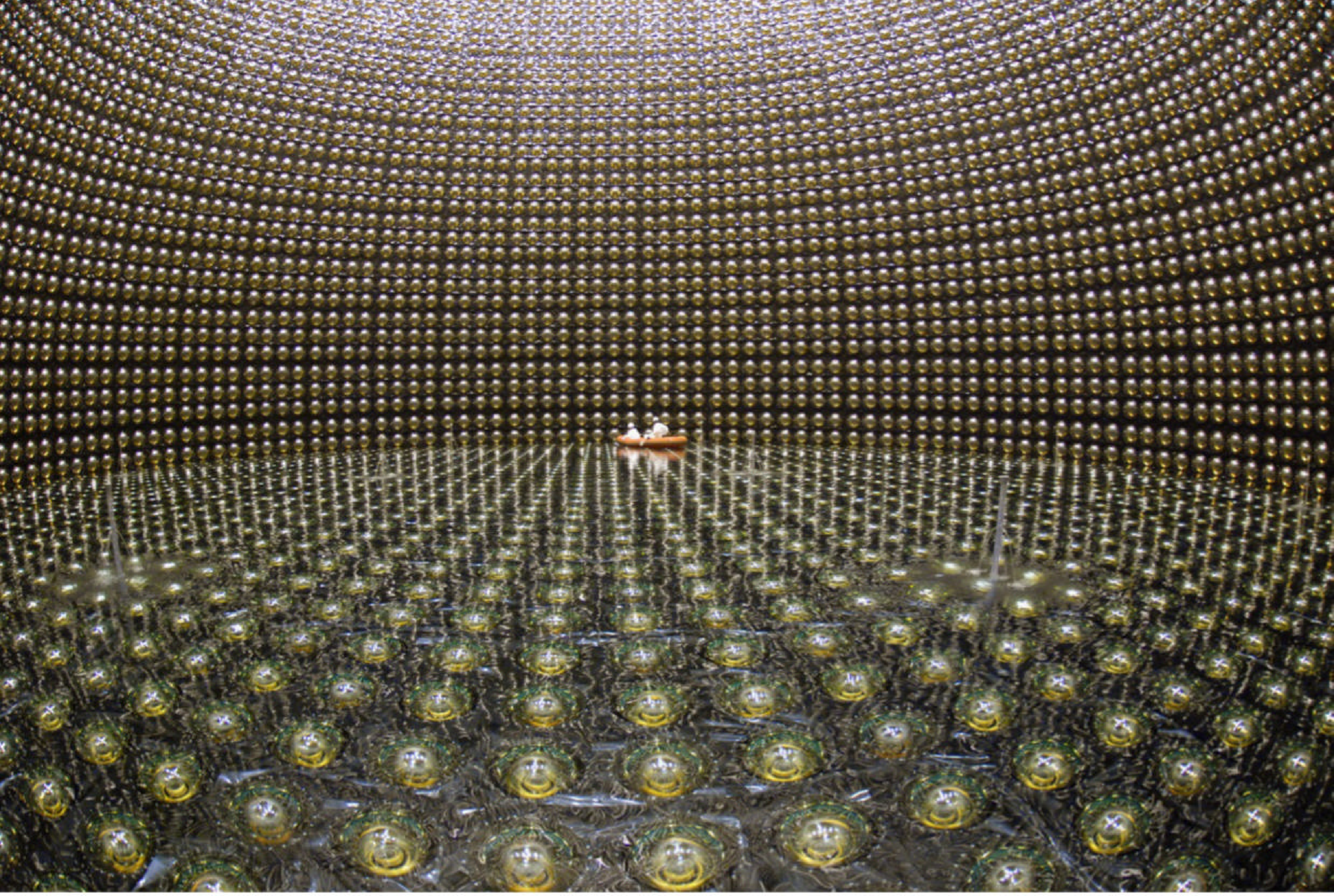
"All the big, interesting events — like supernovae, gamma-ray bursts, and mergers — are disruptive," says Péter Mészáros, a theoretical astrophysicist at Penn State. "They send out accelerated particles, photons, and waves in space-time."

Astronomers call these messengers, and there are four types: photons, neutrinos, cosmic rays, and gravitational waves. Gradually, scientists have unlocked the ability to detect them all. Today, astronomers stand on the brink of a new era of multi-messenger astronomy — one they have been awaiting for decades and that is already providing new insights. Thanks to big instruments, big collaborations, and big data, they finally have the practical tools to interpret the cosmic detritus constantly raining down upon the Earth.

A fuller picture

The roots of multi-messenger astronomy date to the 1960s, when the U.S. government launched satellites carrying detectors for gamma rays — the most powerful photons — to track Russian nuclear tests. They found plenty of gamma-ray sources, but to their surprise, they weren't coming from Earth, but from all around the sky.

"People thought the Russians were making nuclear explosions out in space," says Mészáros. "But soon it was obvious that they were coming from very far away, cosmological distances." Around the same time, astronomers detected neutrinos, which are subatomic particles with no charge and very little mass, emerging from the Sun. Cosmic rays — atomic nuclei that have been accelerated to near the speed of light — were first seen in balloon experiments about 100 years ago. And although Albert Einstein predicted gravitational waves — the ripples in space-time that occur when massive objects collide — in 1916, they were not observed until 2015.



The Super-Kamioka Neutrino Detection Experiment (or Super-Kamiokande) near Hida, Japan, is an underground stainless steel tank that holds 55,000 tons (50,000 metric tons) of water. If a neutrino interacts with a water molecule, it emits light that can be detected by the 13,000 photomultiplier tubes that line the tank's interior. KAMIOKA OBSERVATORY, ICRR (INSTITUTE FOR COSMIC RAY RESEARCH), THE UNIVERSITY OF TOKYO

Multi-messenger astronomy is the practice of synthesizing these various messengers from violent astronomical events. For instance, astronomers have directly observed gravitational waves and used these observations to understand what happens when neutron stars or black holes collide. Astronomers have also uncovered new mysteries, including the discovery that rare ultrahigh-energy cosmic rays originate from outside our galaxy, and that high-energy neutrinos form a cosmic background that pervades the universe. Exciting theories abound as to what kinds of exotic objects are sending out these cosmic messengers: superstrings, dark matter, and even "defects" in the structure of the universe have all been suggested.

"The ultimate goal is to witness an event with all the messengers," says Kate Scholberg, a neutrino physicist at Duke University. "We have come close in the past few years. When it does happen — and it should soon — then hopefully we can get a full picture of the emission source."

The power of these combined messengers comes from the fact that each one is generated by one of the four forces of nature: photons by the electromagnetic force, gravitational waves by gravity, cosmic rays by the strong nuclear force, and neutrinos by the weak nuclear force. The different messengers are the product of their particular origins, and so their presence (or absence) and their characteristics — such as composition, energy level, and direction — teach us about the object they came from.

It has been said that the only limit to success is of imagination, but in this case, the challenges are purely practical.

The trick is that each of the aforementioned messengers requires vastly different detectors and an unprecedented level of cooperation across disciplines. Instantaneous communication is needed to coordinate observations of fleeting events, and processing the data requires bespoke skills in statistical analysis and data mining. It has been said that the only limit to success is of imagination, but in this case, the challenges are purely practical.

Capturing neutrinos

The first object scientists studied with multiple messengers was one close to home: our Sun. In the 1960s, American physicist Raymond Davis Jr. led the first experiment to detect solar neutrinos: a 100,000-gallon (380,000 liters) tank of dry-cleaning fluid placed deep underground in the Homestake Gold Mine in South Dakota. When a neutrino happened to interact with a molecule of that fluid, it transformed into an atom

of argon, which Davis could detect. The observations of solar neutrinos have since been confirmed by others, including the series of Kamiokande detectors using pure liquid water in Japan.

Then, in 1987, neutrino observatories detected emission from a supernova in the Large Magellanic Cloud — two hours before visible light from the stellar explosion reached Earth. That supernova, SN 1987A, was the first that modern astronomers were able to study with multiple messengers. These observations revolutionized our understanding of core-collapse supernovae, eventually providing direct evidence that these events create neutron stars.

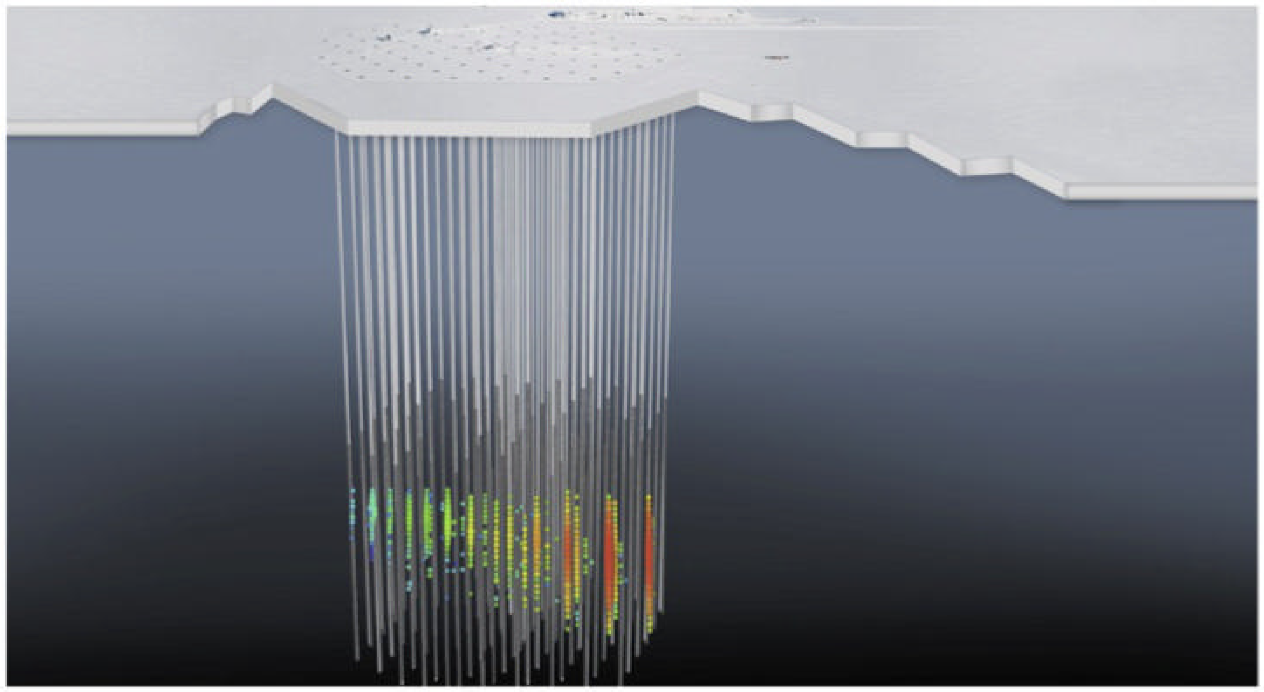
Neutrinos are useful messengers because they travel in a straight, traceable line from their origin, passing through nearly every obstacle in their path. This allows scientists to see into locales that radiation cannot penetrate — but it also makes them difficult to detect.

"Neutrinos only weakly interact with matter," says Julia Tjus, an astroparticle physicist at Ruhr-Universität Bochum in Germany. "So you need huge volumes to catch only a few particles, either in man-made water tanks or, on a much bigger scale, by instrumenting the ocean or the Antarctic ice sheet."

This last option is what has been done with IceCube, a neutrino detector at the South Pole. Ice works better than liquid water — when water sloshes around, it makes it harder to trace neutrinos back to their point of origin in the sky — and Antarctic ice is especially transparent and stable. To detect neutrinos, IceCube also needed to be shielded from radiation at Earth's surface. So scientists drilled with a specially designed hot-water tool into the ice sheet to a depth of about 8,200 feet (2,500 meters), and lowered optical modules on long cables into the holes before they refroze. These sensors detect neutrinos by imaging the secondary particles that radiate from points of impact in the ice.

"The most significant multi-messenger detection out of IceCube so far came from a blazar in 2017," says Tjus. Blazars are a type of galaxy with a central supermassive black hole that shoots out jets of ionized matter at nearly the speed of light. In that event, IceCube's sensors captured the telltale trail of particles from the impact of a single neutrino from a source in the constellation Orion. Follow-up observations from NASA's Fermi Gamma-ray Space Telescope showed that in the same direction lies blazar TXS 0506+056, making it the third known individual source of neutrinos (after the Sun and SN 1987A). Furthermore, the gamma-ray observations showed that the blazar was flaring up at the time.

The detection of these two messengers — a high-energy neutrino and gamma rays — is strong evidence that blazars are a source of high-energy neutrinos. But it also suggests that blazars play a role in generating another mysterious messenger — cosmic rays, which are critical intermediaries in producing those neutrinos.



When a neutrino strikes a molecule of ice, it produces secondary particles that emit light as they pass through the ice. This diagram shows how IceCube's array of optical sensors detected the light produced by the neutrino from blazar TXS 0506+056. The red-to-blue color gradient reflects the sequence of time, with red indicating the sensors triggered first as the particle shower entered the array. ICECUBE COLLABORATION/NSF

The Homestake experiment, seen here in a 1972 archival photo, was constructed in a mile-deep gold mine in South Dakota. U.S. DEPARTMENT OF ENERGY

Cosmic debris

Cosmic rays are high-energy protons and atomic nuclei — the leftovers of matter that has been torn apart. These particles represent the only direct source of samples of material from outside the solar system. They move through space at nearly the speed of light, and their

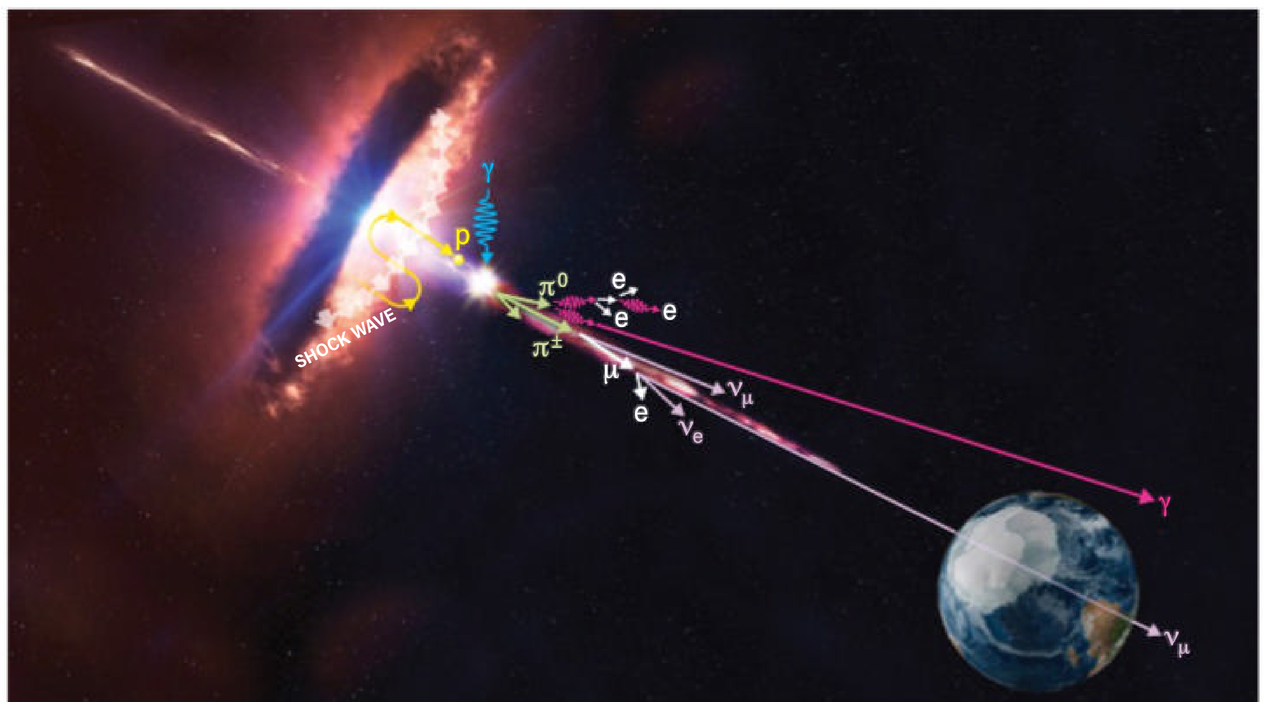
On the plains of Argentina, the 1,660 water tanks of the Pierre Auger Observatory lie scattered across an area the size of Rhode Island, waiting for cosmic rays to strike the atmosphere overhead. These events create an air shower of secondary particles that the 3,170-gallon (12,000 L) tanks are designed to detect as the particles pass through them. PIERRE AUGER OBSERVATORY/STEVEN SAFFI

exact speed and character are determined by the events that accelerate them. When they strike other material, they interact with it, leaving clues in their wake. For instance, when colliding with interstellar dust, they may form bonds between atoms and create complex organic molecules, the building blocks of life. And, scientists suspect, when cosmic rays are ejected from the core of a blazar and interact with surrounding gas, they may generate neutrinos — like the one detected by IceCube in 2017.

That means the next generation of neutrino telescopes will also be useful for investigating cosmic rays. Upcoming facilities like IceCube-Gen2 (an upgrade to the existing array) and the Cubic Kilometre Neutrino Telescope (a planned neutrino detector to be installed at the bottom of the Mediterranean Sea) "should be sensitive enough to see the diffuse neutrino flux that high-energy cosmic rays make as they travel through deep space," colliding with interstellar dust, Tjus says.

Astronomers can also use dedicated observatories to study those cosmic rays that survive the trip to Earth from galactic or even extragalactic events. When they hit Earth's atmosphere, they interact with air molecules, creating showers of secondary particles: X-rays, muons, protons, antiprotons, alpha particles, pions, electrons, positrons, and neutrons. The largest facility designed to capture this subatomic shrapnel is the Pierre Auger Cosmic Ray Observatory, which uses more than 1,600 massive water tanks spread out over 1,160 square miles (3,000 square kilometers) in western Argentina.

Astronomers think that most cosmic rays originating within our galaxy are accelerated by shock waves produced by supernovae. But Pierre Auger has also



ASTRONOMY: ROEN KELLY, AFTER ICECUBE/NASA

TRAIL BLAZARS

The voracious black holes at the centers of blazars are the most powerful particle accelerators in the cosmos, capable of producing multiple types of messengers, including gamma rays and neutrinos.

The process starts with the blazar's jets of matter, which shoot out into space, forming a shock wave as they plow into surrounding material. The charged particles streaming away from the shock generate magnetic fields that scatter particles back and forth across the shock boundary, gaining energy from the shock every time. This can accelerate protons to nearly the speed of light, turning them into cosmic rays (p).

If these cosmic rays collide with photons, they may produce particles called pions. These can be neutral pions (π^0), which decay to gamma rays as well as some electrons and positrons (both denoted by e).

Alternatively, the pions may have a charge ($\pi^\pm$), in which case they decay to a muon (μ) and a muon neutrino (ν_μ) — one of three "flavors" of neutrinos. The muons decay further to an electron or positron (e) and either a muon neutrino or an electron neutrino (ν_e, another flavor of neutrino).

These messengers then carry on streaming through the universe — perhaps to be captured and counted by detectors at Earth.

seen very rare ultrahigh-energy cosmic rays. In 2017, Pierre Auger researchers reported these cosmic rays appear to originate outside our galaxy. While they suspect actively feeding supermassive black holes produce them, a true multi-messenger detection that includes cosmic rays is needed to verify that theory.

Across the spectrum

Astronomers have been studying the cosmos with electromagnetic radiation ever since people first looked at stars with the naked eye. But beyond visible light, the electromagnetic spectrum includes all types of electromagnetic radiation: radio waves, microwaves, infrared and ultraviolet light, X-rays, and gamma rays. These last two are blocked by Earth's atmosphere, so astronomers must rely on spacecraft like Fermi and NASA's Neil Gehrels Swift Observatory.

Gamma rays are produced mainly by nuclear reactions: fusion, fission, and atomic decay. Gamma-ray bursts (GRBs) are born from the explosion of a massive star or the collision of neutron stars. In a matter of seconds, GRBs put out as much energy as the Sun puts out in billions of years. "Gamma rays are the most energetic kind of radiation, so this tells us that something massive has happened," says Paul O'Brien of Leicester University, who has been part of the Swift team for nearly two decades.

Swift acts as an eye in the sky, constantly scanning the cosmos for GRBs. But GRBs are brief and easy to miss. To maximize the chances of spotting one, Swift teams up with gravitational-wave detectors. "If the gravitational wave guys tell us they saw something, we have to move quickly, to point in that direction and try to find it," says O'Brien.

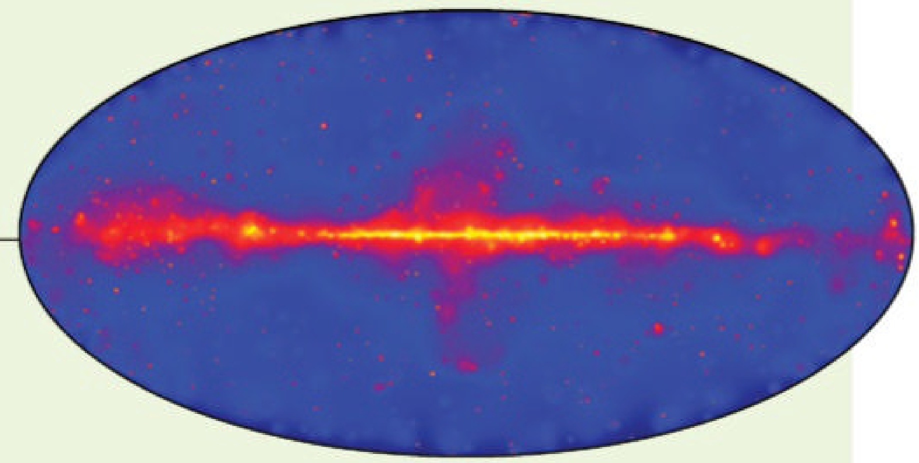
The observations complement each other: Gravitational waves are the fastest messenger, but current gravitational wave instruments aren't able to accurately localize the exact source of events. On the other hand, X-rays and gamma rays are very useful in this regard.

"But Swift is getting on," O'Brien says. The Space Variable Objects Monitor (SVOM), a joint project between China and France, is a small satellite in the vein of Swift but with new capabilities. It's planned for a June 2022 launch. The European Space Agency (ESA) also has

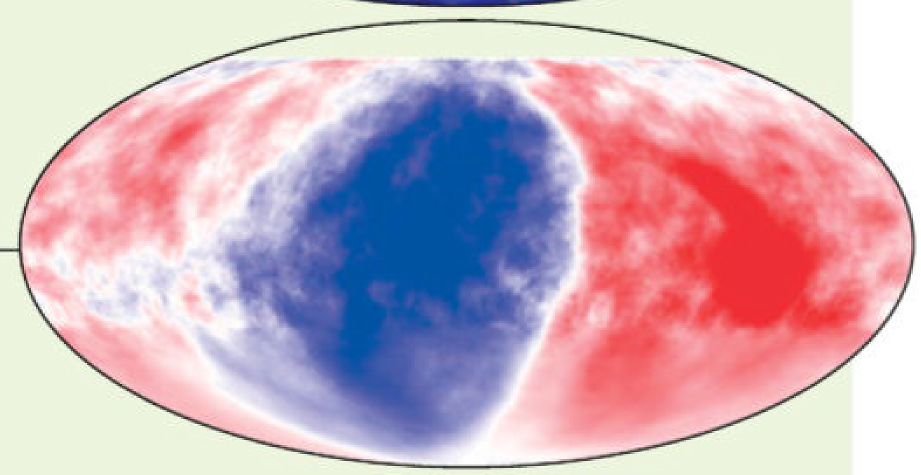
A SKY FULL OF MESSENGERS

As more observatories that are capable of detecting different types of messengers come online, astronomers are slowly gaining new views of our cosmic surroundings.

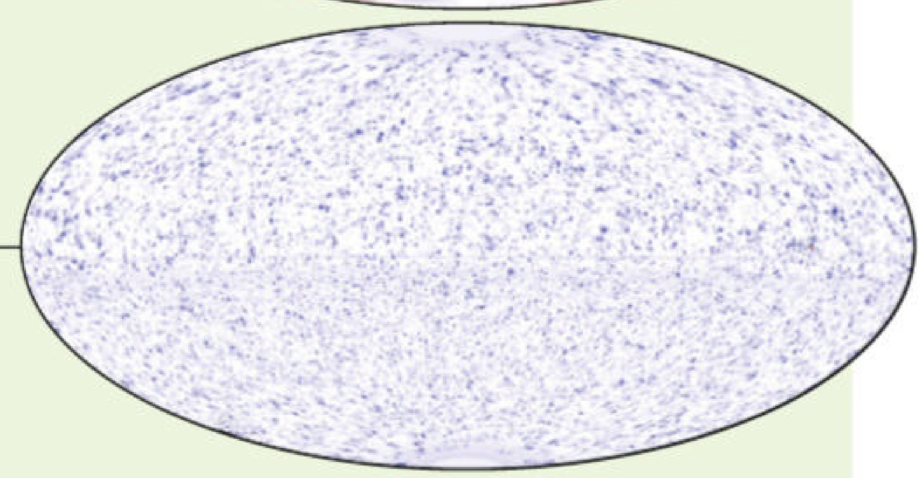
Visible: One of the most comprehensive maps of the visible sky ever made, this familiar view of the Milky Way Galaxy comes from ESA's Gaia spacecraft.



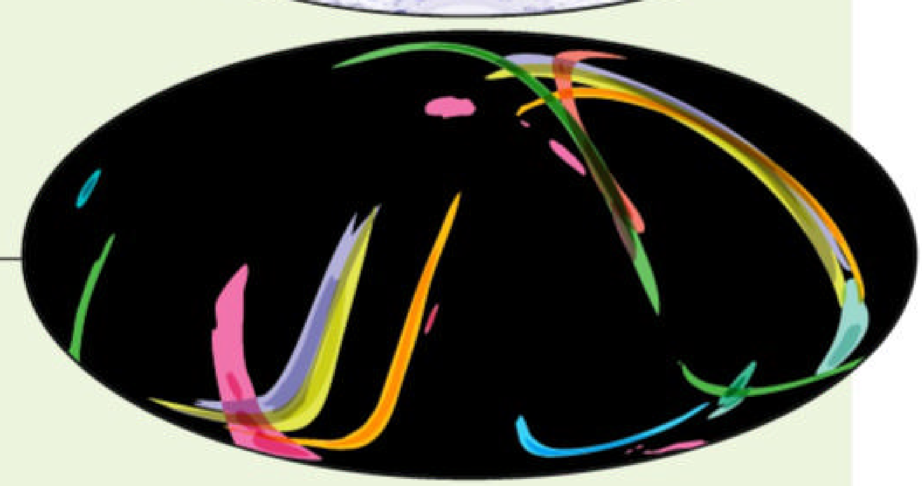
Gamma rays: This view from NASA's Fermi space telescope reveals gamma-ray sources ranging from pulsars in our own galaxy to distant blazars. The galactic disk appears flat due to the use of galactic coordinates.



Cosmic rays: This map of the cosmic ray sky, produced by IceCube and the High Altitude Water Cherenkov Observatory, is less detailed but shows that more ultrahigh-energy cosmic rays are coming from one side of the sky (shown in red) than the other (in blue). Astronomers aren't yet sure what causes this imbalance.



Neutrinos: IceCube's all-sky neutrino map is also in its early stages of being collected, and individual sources are only on the verge of detection.



Gravitational waves: The plotted areas are astronomers' best estimate of the origins of LIGO/Virgo's first 11 gravitational wave detections. When additional gravitational facilities come online, they should help pinpoint future sources with greater precision.

FROM TOP: ESA/GAIA/DPAC; NASA/DOE/FERMI LAT COLLABORATION; *ASTRONOMY*: ROEN KELLY, AFTER ABEYSEKARA ET AL. (2019); ICECUBE COLLABORATION; LIGO/VIRGO

Cosmic rays are thought to be produced in remnants of supernovae like SN 1987A, seen at the center of this Hubble Space Telescope image. The expanding shock waves of these stellar explosions can accelerate protons to near the speed of light. NASA, ESA, R. KIRSHNER (HARVARD-SMITHSONIAN CENTER FOR ASTROPHYSICS AND GORDON AND BETTY MOORE FOUNDATION), AND M. MUTCHLER AND R. AVILA (STSCI)

a large observatory planned for the 2030s: the Advanced Telescope for High-ENergy Astrophysics (ATHENA). These detectors are needed, says O'Brien, "because without space-based transient monitors, we don't get the high-energy signal. And that's a critical part of the whole message."

On May 22, 2020, Northwestern University's Wen-Fai Fong received a more mundane kind of message: an email straight from Swift, announcing a GRB. "When they see one, it triggers an automatic mail-out," she says. "I got a notification on my phone, and quickly contacted the Very Large Array (VLA), then Hubble."

Fong was able to collect some good data from the VLA, which helped her secure precious time on the Hubble Space Telescope. This added vital information to the GRB that Swift detected. Ultimately, she and her team were able to capture five messengers from the event: X-rays, optical light, infrared light, radio waves, and gamma rays.

Fong had found something special. Although the event was very bright, it clearly wasn't a nova or supernova. It was a little too dim, and with faster ejecta. She concluded it was a kilonova: a burst created by a neutron star colliding with a black hole or — in this case — another neutron star.

Fong's study is a significant contribution to the theory that a collision of two neutron stars forms a magnetar — a kind of super neutron star with a powerful magnetic field, which has recently been shown to produce high-energy X-rays and gamma rays. Roughly 30 magnetars have been discovered — all in our galaxy — and Fong's multi-messenger work ties them together with kilonovae and GRBs.

The resulting kilonova also produces gravitational waves on a grander scale than supernovae. But, "sadly, the gravitational-wave facilities are currently offline, so they couldn't corroborate," says Fong. That's because the Laser Interferometer Gravitational-wave Observatory (LIGO) in the U.S. and the Virgo detector in Italy are undergoing upgrades in preparation for their next observing run, set to start next year.

Catching waves

Einstein predicted gravitational waves, the most elusive of the messengers, in the early 20th century on the basis of his general theory of relativity. Unlike the messengers of the other three forces, they are not particles, but disturbances in the fabric of space-time that propagate outward at the speed of light and are created when matter is accelerated. The effects of these waves passing through Earth are so small and brief that the LIGO-Virgo detector arms, which range from 1.86 to 2.46 miles long (3 to 4 km), measure a distortion of only 1/10,000 the width of a proton over a fraction of a second. The first gravitational-wave detectors were built in the 1970s, but it took several decades to improve their sensitivity enough for functional observing.

Since that long-awaited 2015 detection, subsequent observations have been trickling in — a few the next year, more the next. Then, in just the first half of the third observing run (from April to October 2019), an incredible 39 gravitational-wave events were detected. This has been game-changing for the field — gone are the days when astronomers caught only one big multi-messenger event a decade. And as gravitational waves are the fastest of all the messengers, our chances of capturing an event are higher than ever.

LIGO-Virgo's third observing run was game-changing for the field — gone are the days when astronomers caught only one big multi-messenger event a decade.

To identify these events and sort them from the noise, the LIGO and Virgo teams use advanced signal processing and analysis methods, including machine learning. This illustrates an emerging new specialty in the field that combines skill sets from astronomy, statistics, and computer science. Even though these scientists have no amalgamated title as of yet, à la *astrophysicist*, their

work is vital. The ability to quickly — and accurately — identify events in observational data so that alerts can be sent out to the rest of the astronomical community rests upon their software.

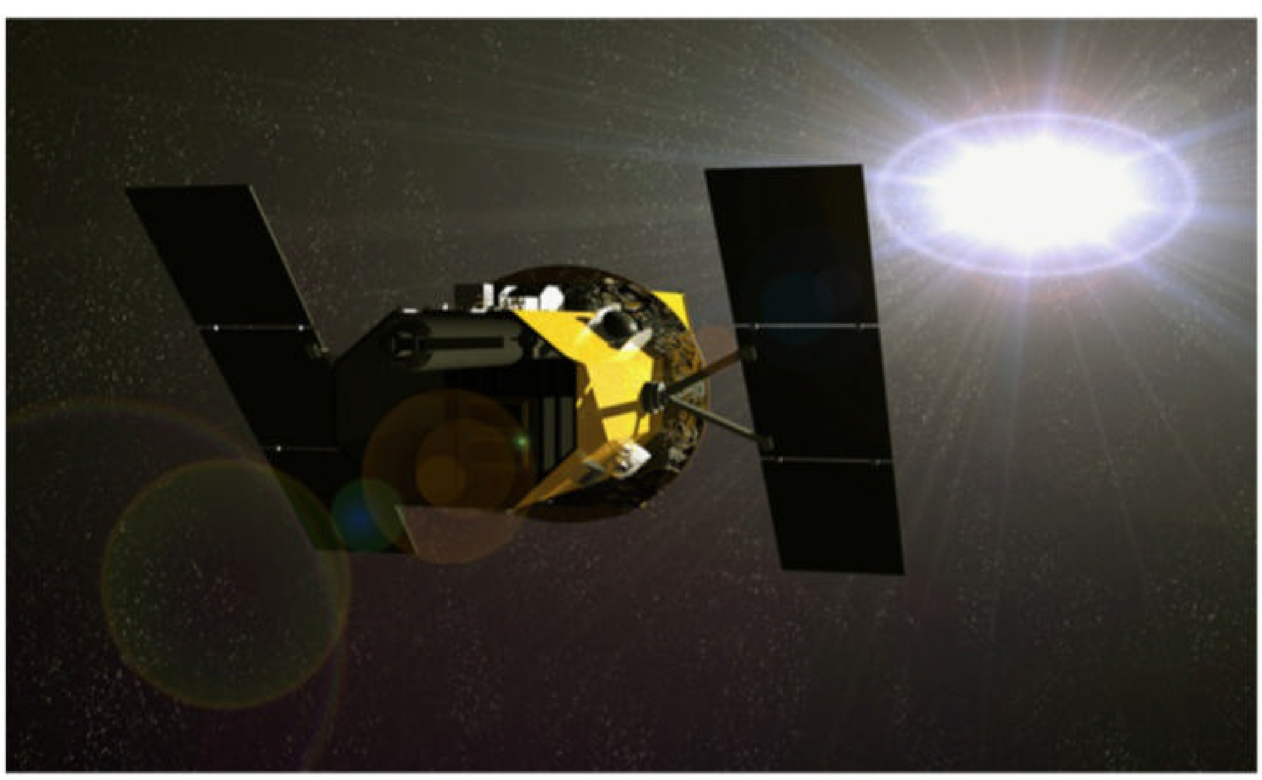
"Not all events produce all messengers," says LIGO team member Lilli Sun of Australian National University. "For example, we will not expect to see [electromagnetic] radiation after a binary black hole merger." She notes that one particularly remarkable detection in 2017, a neutron star merger, "had everything except neutrinos. We tried to see them but didn't. We don't know why exactly — it is possible that we were not facing the event exactly right. This remains a goal, because indeed we are expecting to see them."

The detector arms of LIGO's Livingston Observatory in Louisiana (seen here) — as well as its twin Hanford Observatory in Washington — stretch for 2.46 miles (4 km). CALTECH/MIT/LIGO LAB

Working together

Multi-messenger detection capabilities are only set to grow more powerful. All the major facilities involved are either currently undergoing upgrades — like Pierre Auger — or have imminent plans to do so. IceCube-Gen2 is due to be deployed during the Antarctic summer of 2022–2023. The Japanese Kamioka Gravitational Wave Detector has recently begun operations and hopes to achieve its target sensitivity by 2024. In addition to the ongoing Advanced LIGO-Virgo upgrade, a new LIGO facility is currently being built in India. And ESA has plans to build a space-borne gravitational-wave observatory, the Laser Interferometer Space Antenna, scheduled for launch in the early 2030s. These new facilities, with their improvements in resolution and sensitivity, will allow for more and better detections, and hopefully even solve some long-standing mysteries.

"There are many things we hope to learn in the next few decades," Sun says, "such as what is at the center of a neutron star, and the exact conditions which determine whether a merger creates a compact object or a black hole. We also hope to see different kinds of gravitational waves, perhaps ones from continuous sources. And it could be that gravitational waves can teach us about dark matter," the mysterious stuff that makes up most of the matter in the universe and holds together galaxies with its gravitational glue.



Since its launch in 2004, NASA's Neil Gehrels Swift Observatory has served as a sentry, keeping watch for gamma-ray bursts across the sky. NASA

Multi-messenger astronomy might even hold clues to resolving one of the most fundamental problems in all of science: the fact that the standard model of physics unifies only three of the four known forces (electromagnetic, strong, and weak). General relativity, which describes how gravity arises from the curvature of space-time, also explains the behavior and evolution of the cosmos, but from a different point of view. Yet these two theories become inconsistent with each other at the smallest level, such as the center of a black hole or the moment of the Big Bang. Can they both be right? Can they be unified into a "Theory of Everything?"

Perhaps multi-messenger astronomy has the answer. Perhaps by combining information from all four forces, we can penetrate to the tiniest, earliest core of astronomical-scale phenomena and take a quantum leap in our understanding of how the universe actually works.

Like the old parable that teaches us blind men cannot make sense of an elephant by touching just one part of its body, the big picture of massive astronomical objects and events can only be made clear when all possible sources of information are gathered and synthesized. Perhaps then, we will be able to approach the grand unification of the forces and finally make sense of it.

Arwen Rimmer *is a writer and musician in Cambridge, England.*

Visible to the naked eye
Visible with binoculars
Visible with a telescope

THE SOLAR SYSTEM'S CHANGING LANDSCAPE AS IT APPEARS IN EARTH'S SKY.

BY MARTIN RATCLIFFE AND ALISTER LING

JUNE 2021 The planets are out to play

Mars crosses the stunning Beehive Cluster (M44) this month, just as it did in this 2010 image. TUNÇ TEZEL

OBSERVING HIGHLIGHT

VENUS meets up with open star cluster M35 in Gemini the evening of June 3. The pair stand 30' apart in twilight.

An annular solar eclipse crosses parts of northern Ontario this month. Easier targets for observers include the wonderful spectacle of Mars crossing the Beehive star cluster, while Venus dazzles in the early evening sky. The solar system's two giant planets, Jupiter and Saturn, perform well in the early morning hours. Uranus and Neptune are fine binocular objects, both moving close to similarly bright stars this month. Lastly, Mercury attempts to show itself in the last few days of June, but it's low and difficult in bright twilight.

Venus is the first planet to appear after sunset. It's low in the western sky at 6° elevation 45 minutes after sunset on June 1. At magnitude –3.9, it easily punctuates the twilight glow and remains visible until nearly 10 P.M. local time.

Locate Venus June 3 and scan east with binoculars as the sky darkens. Can you spot M35, a well-known 5th-magnitude open cluster in Gemini the Twins, roughly 30' from the bright planet?

Venus and a slender crescent Moon meet the evening of June 11, less than 3° apart. The planet is at its most northerly declination for the year and also reaches perihelion on the 12th. So, while Venus closely follows the Sun, its visibility stays good throughout June.

Venus continues across Gemini and is in line with Castor and Pollux on June 24, just over 6° south of Pollux. By the end of June, Venus is nearly halfway across Cancer the Crab and ends the month 2.7° shy of the Beehive Cluster (M44). As with M35, see if you can spot the cluster to Venus' east though binoculars in twilight as the pair descends toward the western horizon.

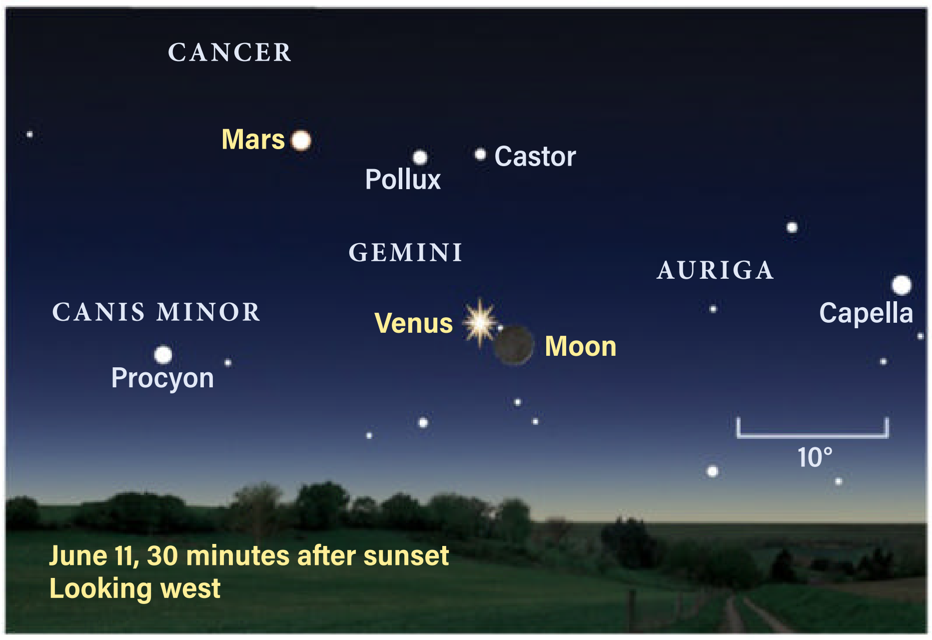
Telescopically, Venus changes very little this month. It's on the far side of the Sun, revealing a 95-percent-lit disk June 1 that wanes to 90 percent lit by June 30. Meanwhile, the span of the disk grows from 10" to 11" in the same period.

Mars begins the month 5.5° due south of Pollux in Gemini and sets just before midnight in early June. The Red Planet shines at a bright magnitude 1.7, nearly 0.2 magnitude dimmer than nearby Castor. The planet's orange hue contrasts nicely with the star's A-type white glow; yellow-orange Pollux, a K-type giant, is a closer match for Mars.

June 13 combines a three-day-old crescent Moon, Mars, and the Beehive Cluster. The cluster stands 4.5° southeast of the Moon, with Mars 3° southwest of our satellite.

Mars crosses the 1.5°-wide Beehive June 22 and 23. Now magnitude 1.8, the ruddy planet provides a stunning contrast to the stars of Praesepe (another name for M44). Catch the view through a low-powered telescope, but do it early — the grouping is low in the west and you'll need a clear horizon to follow it as the sky darkens. Mars sets just before 11 P.M. local time.

An evening star and a crescent Moon



The crescent Moon passes close to Venus the evening of June 11, with Mars also visible nearby. ALL ILLUSTRATIONS: *ASTRONOMY*: ROEN KELLY

Mars ends June still at magnitude 1.8. On the 30th, it lies 4.5° east of M44 and sets around 10:30 P.M. local time. Venus is catching up with Mars — it is now just over 7° west of the Red Planet. Mars remains in the evening sky for several months more, but its great distance from Earth renders a 4"-wide disk — a challenging object even with a telescope. Despite its lack of detail, the Red Planet remains interesting as it traverses the constellations of the ecliptic.

Saturn appears above the eastern horizon soon after midnight local time on June 1, and about two hours earlier on June 30. The planet starts June at magnitude 0.4 and brightens by 0.1 magnitude during the month. Saturn is located in the mid-northern part of Capricornus the Sea Goat and

— Continued on page 38

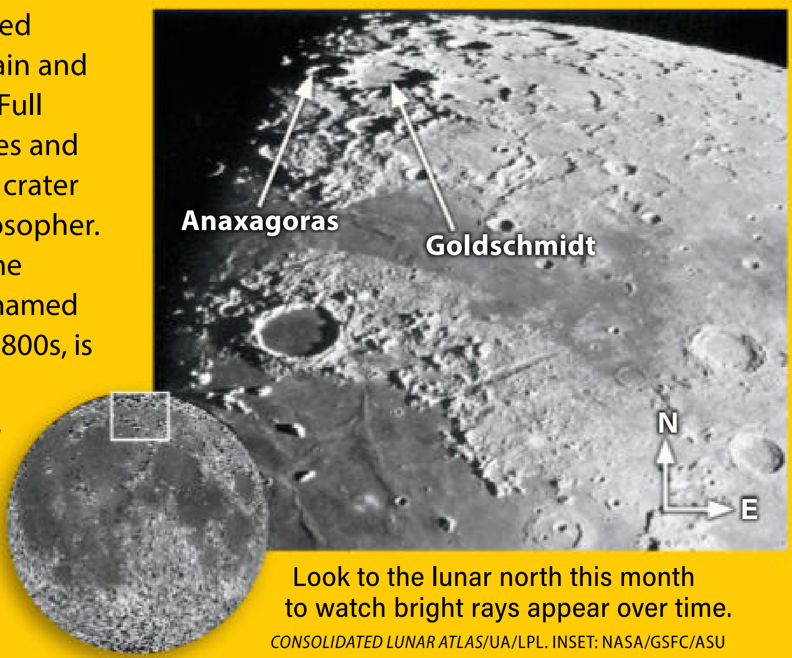
RISING MOON | Splendid spray

REMINISCENT OF SEASONAL CHANGES in Earth's polar regions, the lunar north transforms every month from creeping, cratered shadows to an expansive reflective domain and back again. On the 24th, the high Sun at Full Moon blankets the zone with gray patches and white rays converging toward the young crater Anaxagoras, named after the Greek philosopher.

The progression begins on the 18th, one evening after First Quarter. Goldschmidt, named for a German amateur observer from the 1800s, is a considerable 75 miles wide and sports a freckled floor and a low rim. The relentless bombardment that wore it down has left rounded shadows that extend across its notably shallow floor. Return the next evening, when sharp-edged Anaxagoras has rotated into the light. Its deep insides remain in shadow for another day. Notice how it is carved onto the edge of the sprawling and shallow Goldschmidt. As we near Full Moon, insert a filter or pump up the power to cut down on the glare. Watch Anaxagoras turn into the brightest splotch of rays in the north.

Goldschmidt is similar in age to Tycho and would be just as famous if its impactor had hit at a more convenient latitude, instead of leaving a mark that is foreshortened in the far lunar north. The rays are beautifully defined and evenly spread and the bright, large apron almost obscures its older neighbor. By comparison, the ray system of the much more famous Copernicus appears disorganized.

Anaxagoras and Goldschmidt



Look to the lunar north this month to watch bright rays appear over time.
CONSOLIDATED LUNAR ATLAS/UA/LPL. INSET: NASA/GSFC/ASU

40° Jupiter's altitude an hour before sunrise on June 30 — the highest the gas giant has been in Northern Hemisphere skies for four years.

METEOR WATCH | Shine bright at night

Noctilucent clouds

Last year's Comet C/2020 F3 (NEOWISE) floats amid breathtaking noctilucent clouds over the skyline of Moscow.
DMITRY KOLESNIKOV

THERE ARE NO major meteor showers this month — a lull before late summer, when the shows pick up again. There are minor showers but they are hard to track, generating only a handful of observable meteors per hour. Regularly recording summer meteors helps researchers track these minor showers, so check with the International Meteor Organization (http://imo.net) to help.

Be on the lookout for noctilucent (night-glowing) cloud activity. These pearly clouds appear 50 miles high — more than 10 times the altitude of cirrus clouds. They are produced when ice crystals form on high-flying dust particles. Noctilucent clouds appear between latitudes of 55° and 70° north, remaining in sunlight for hours after sunset during summer. They are usually seen toward the northern horizon.

STAR DOME

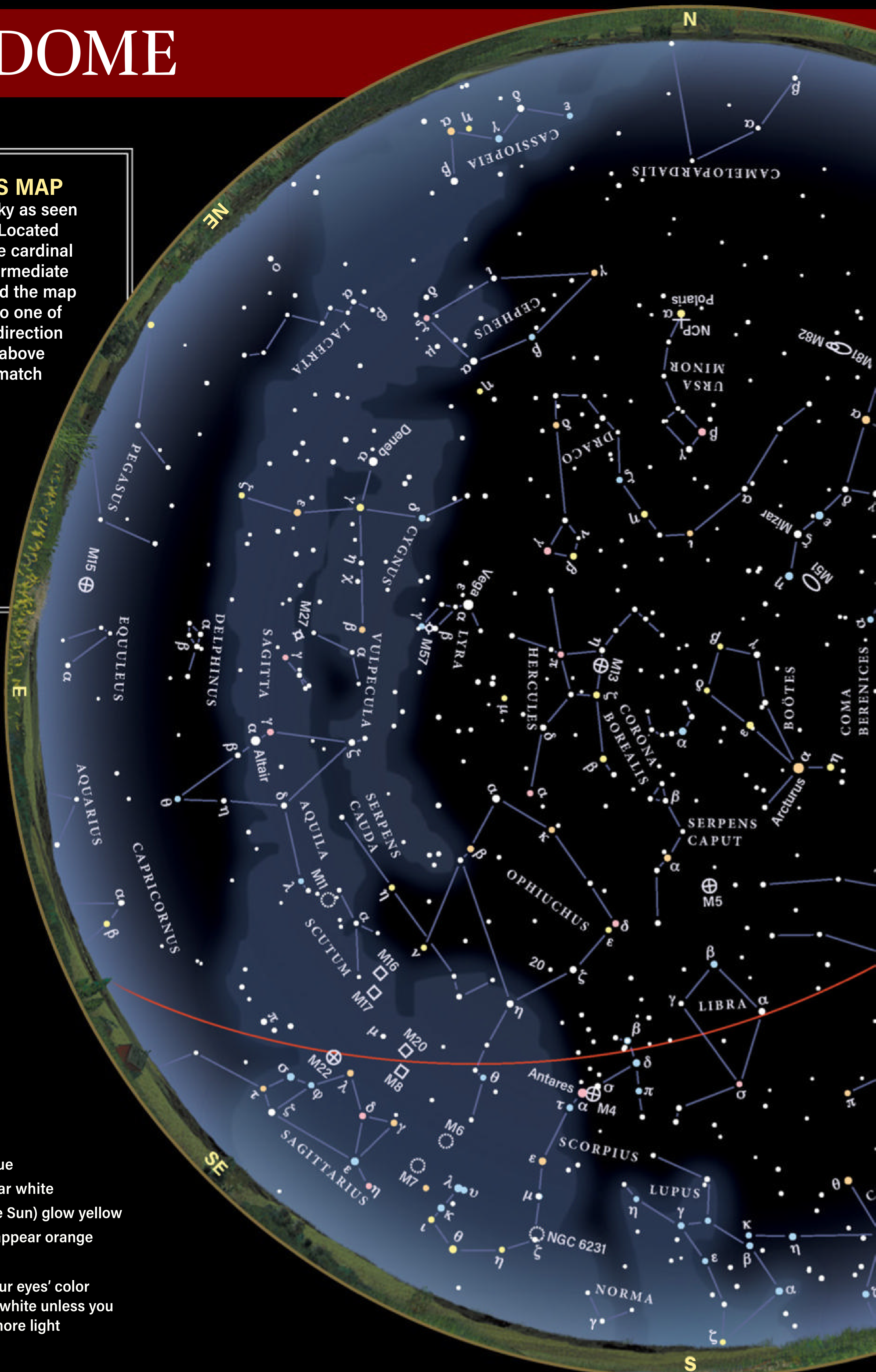
HOW TO USE THIS MAP

This map portrays the sky as seen near 35° north latitude. Located inside the border are the cardinal directions and their intermediate points. To find stars, hold the map overhead and orient it so one of the labels matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

The all-sky map shows how the sky looks at:

midnight June 1
11 P.M. June 15
10 P.M. June 30

Planets are shown at midmonth



MAP SYMBOLS

- Open cluster
- Globular cluster
- Diffuse nebula
- Planetary nebula
- Galaxy

STAR MAGNITUDES

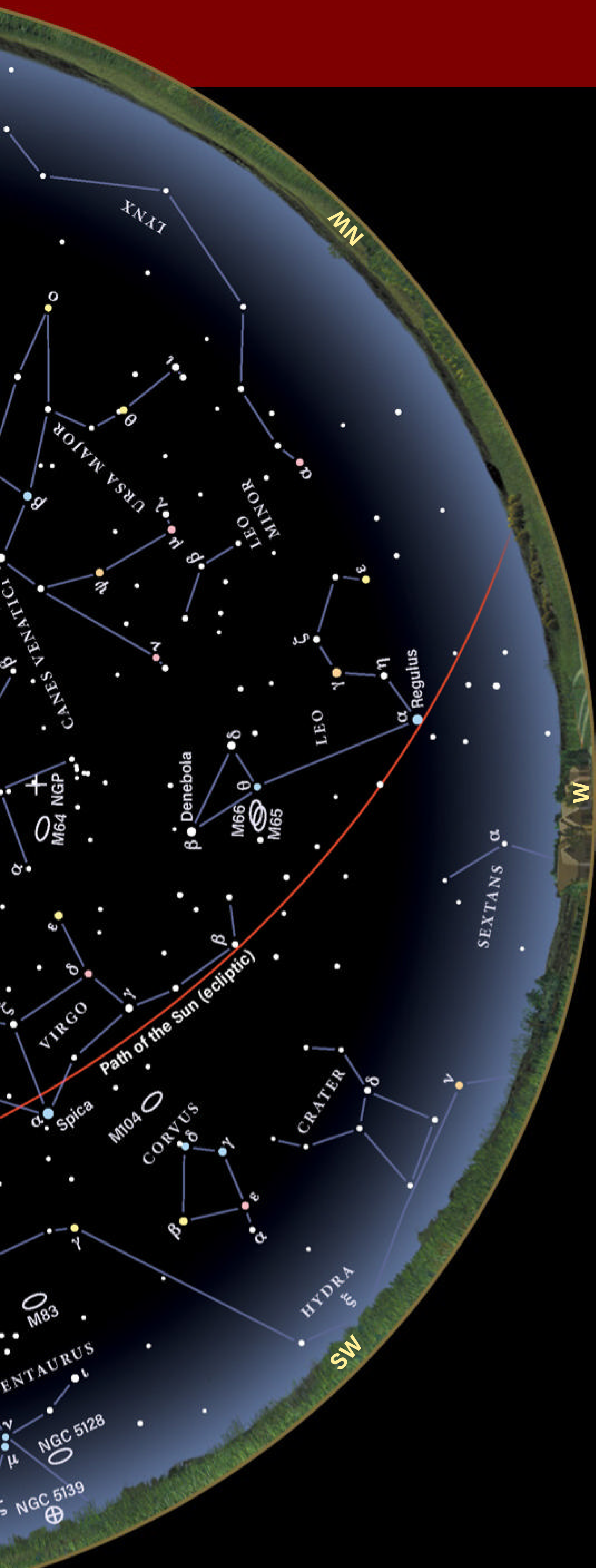
- Sirius
- 0.0
- 1.0
- 2.0
- 3.0
- 4.0
- 5.0

STAR COLORS

A star's color depends on its surface temperature.

- The hottest stars shine blue
- Slightly cooler stars appear white
- Intermediate stars (like the Sun) glow yellow
- Lower-temperature stars appear orange
- The coolest stars glow red
- Fainter stars can't excite our eyes' color receptors, so they appear white unless you use optical aid to gather more light

BEGINNERS: WATCH A VIDEO ABOUT HOW TO READ A STAR CHART AT **www.Astronomy.com/starchart.**



JUNE 2021

SUN.	MON.	TUES.	WED.	THURS.	FRI.	SAT.
		1	2	3	4	5
6	7	8	9	10	11	12
13	14	15	16	17	18	19
20	21	22	23	24	25	26
27	28	29	30			

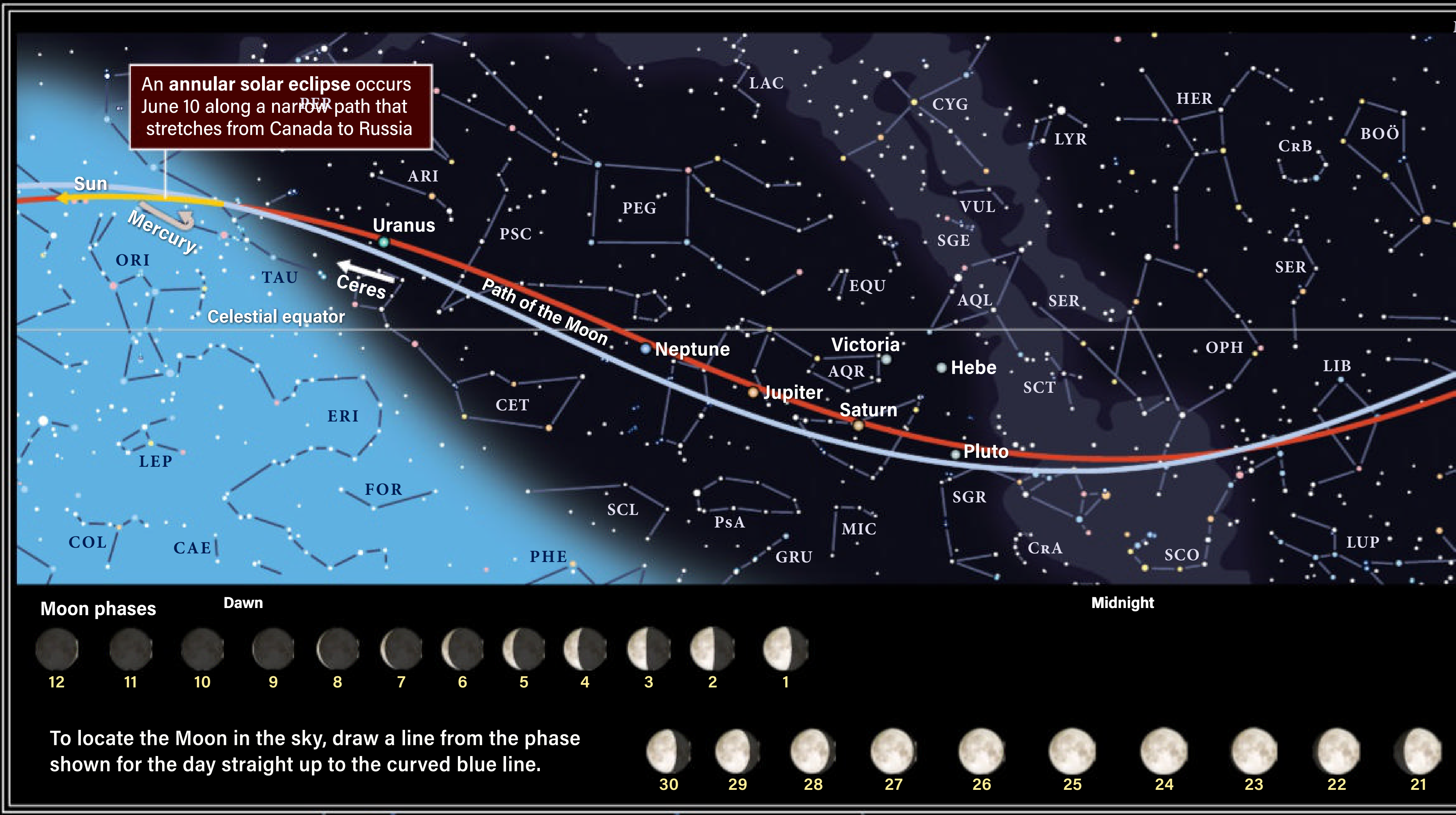
ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

Note: Moon phases in the calendar vary in size due to the distance from Earth and are shown at 0h Universal Time.

CALENDAR OF EVENTS

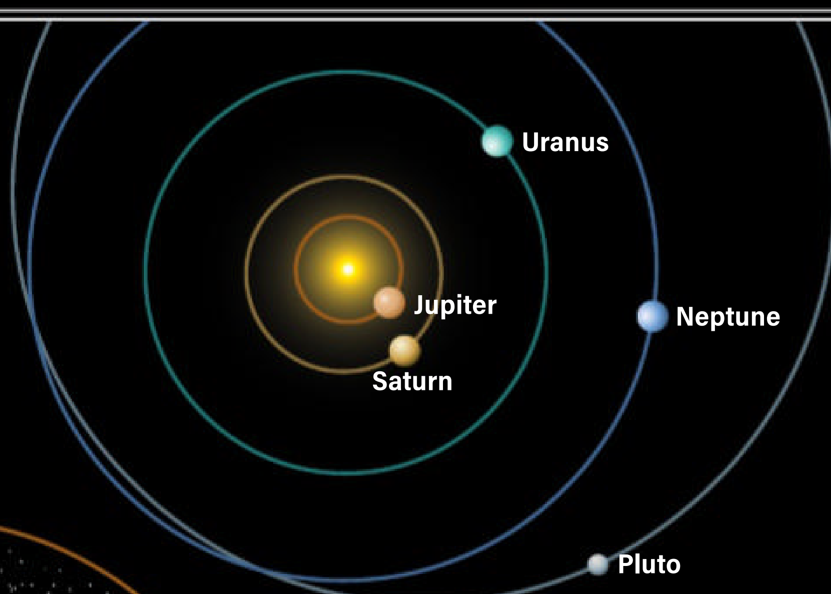
1	The Moon passes 5° south of Jupiter, 5 A.M. EDT
2	Last Quarter Moon occurs at 3:24 A.M. EDT
	Mars passes 5° south of Pollux, 10 A.M. EDT
	The Moon passes 4° south of Neptune, 9 P.M. EDT
6	Asteroid Juno is at opposition, 6 P.M. EDT
7	The Moon passes 2° south of Uranus, 2 A.M. EDT
	The Moon is at apogee (252,418 miles from Earth), 10:27 P.M. EDT
10	New Moon occurs at 6:53 A.M. EDT; annular solar eclipse
	Mercury is in inferior conjunction, 9 P.M. EDT
12	The Moon passes 1.5° north of Venus, 3 A.M. EDT
13	The Moon passes 3° north of Mars, 4 P.M. EDT
17	First Quarter Moon occurs at 11:54 P.M. EDT
20	Summer solstice occurs at 11:32 P.M. EDT
21	Jupiter is stationary, 1 A.M. EDT
22	Venus passes 5° south of Pollux, 11 A.M. EDT
	Mercury is stationary, 7 P.M. EDT
23	The Moon is at perigee (223,666 miles from Earth), 5:55 A.M. EDT
24	Full Moon occurs at 2:40 P.M. EDT
26	Neptune is stationary, 6 A.M. EDT
27	The Moon passes 4° south of Saturn, 5 A.M. EDT
28	The Moon passes 4° south of Jupiter, 3 P.M. EDT
30	The Moon passes 4° south of Neptune, 5 A.M. EDT

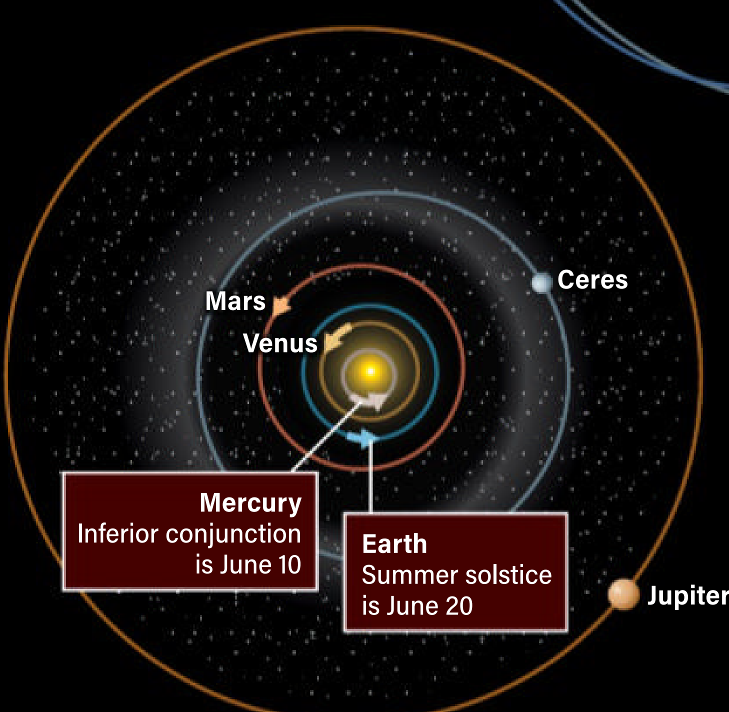
PATHS OF THE PLANETS



THE PLANETS IN THEIR ORBITS

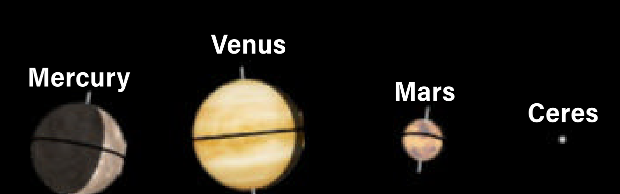
Arrows show the inner planets' monthly motions and dots depict the outer planets' positions at midmonth from high above their orbits.





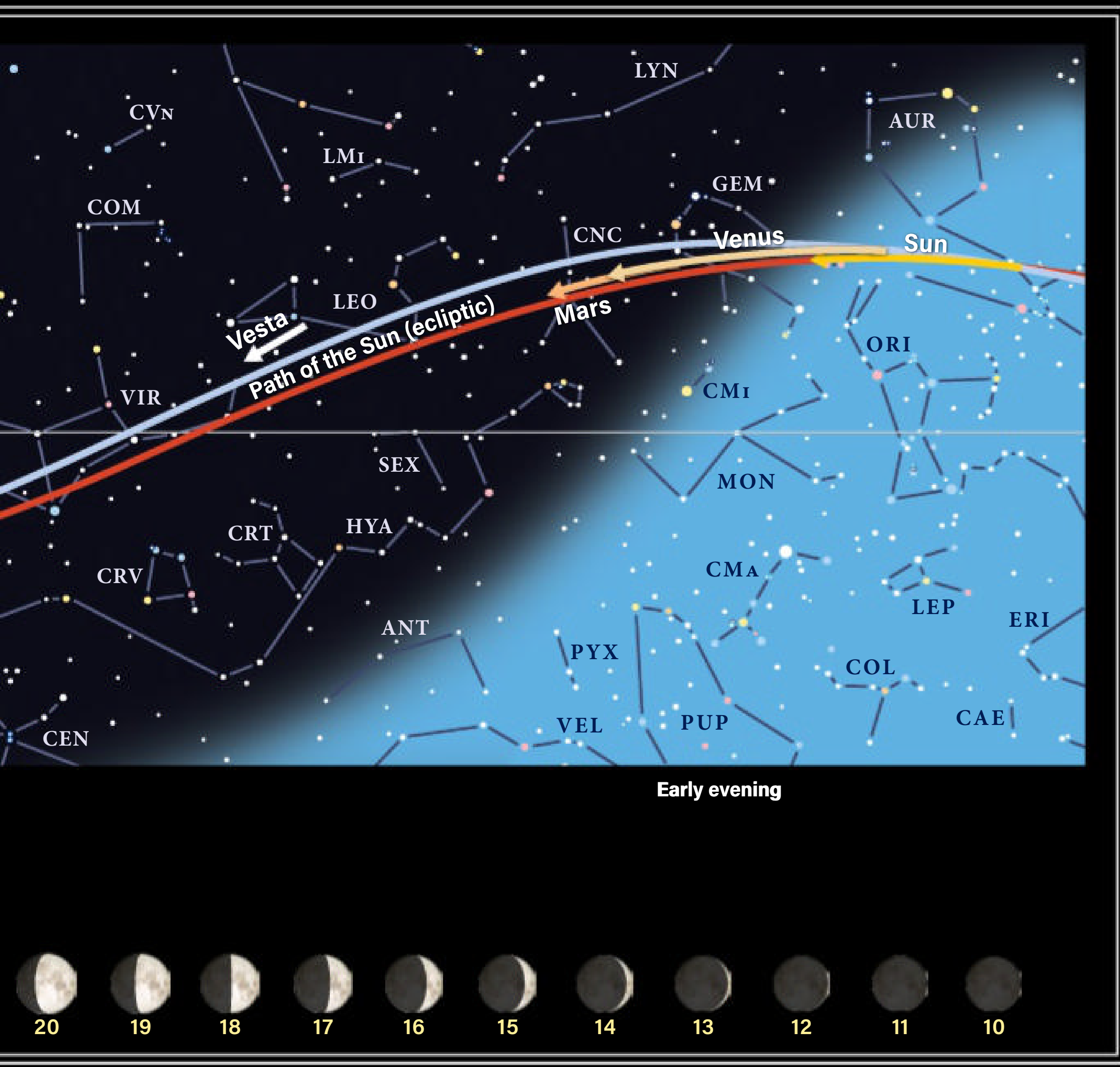
THE PLANETS IN THE SKY

These illustrations show the size, phase, and orientation of each planet and the two brightest dwarf planets at 0h UT for the dates in the data table at bottom. South is at the top to match the view through a telescope.



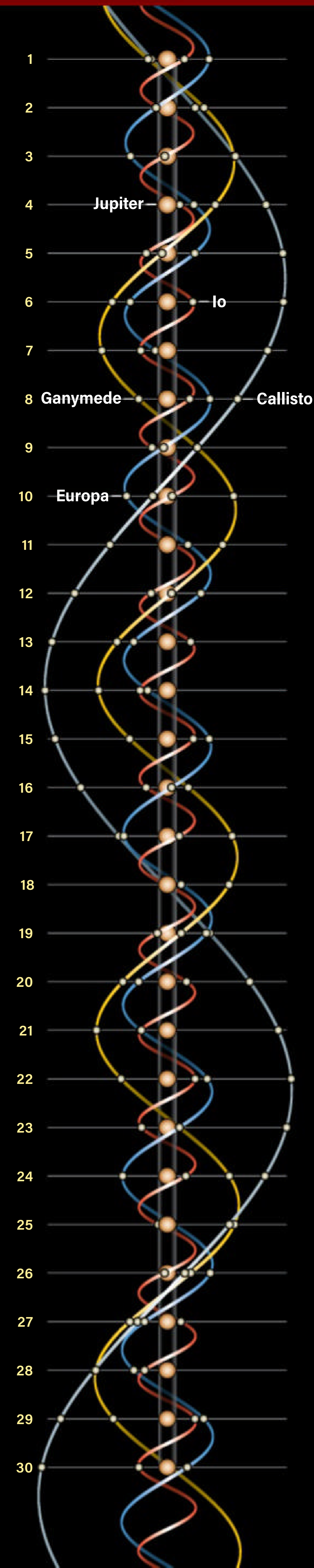
PLANETS	MERCURY	VENUS
Date	June 30	June 15
Magnitude	1.0	–3.9
Angular size	9.0"	10.7"
Illumination	25%	93%
Distance (AU) from Earth	0.746	1.566
Distance (AU) from Sun	0.414	0.718
Right ascension (2000.0)	5h08.5m	7h05.3m
Declination (2000.0)	19°01'	23°56'

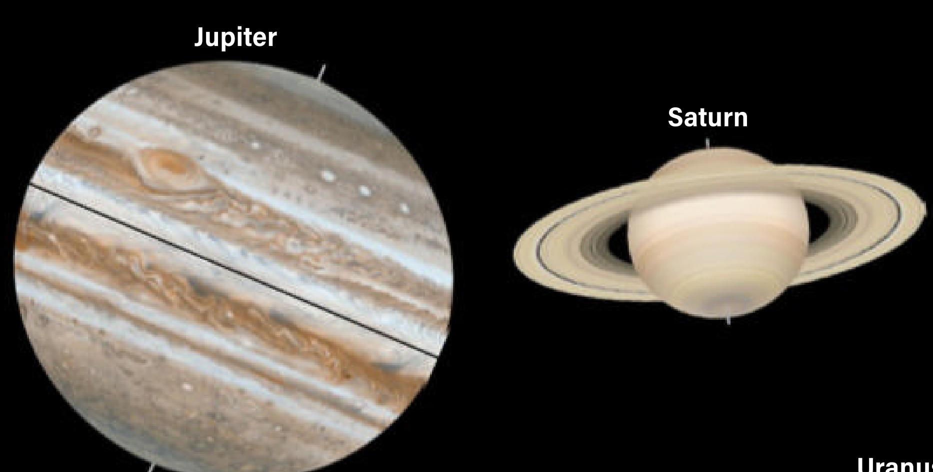
This map unfolds the entire night sky from sunset (at right) until sunrise (at left). Arrows and colored dots show motions and locations of solar system objects during the month.

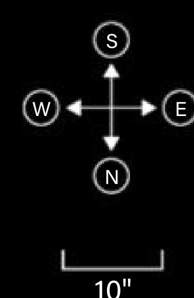


JUPITER'S MOONS

Dots display positions of Galilean satellites at 4 A.M. EDT on the date shown. South is at the top to match the view through a telescope.





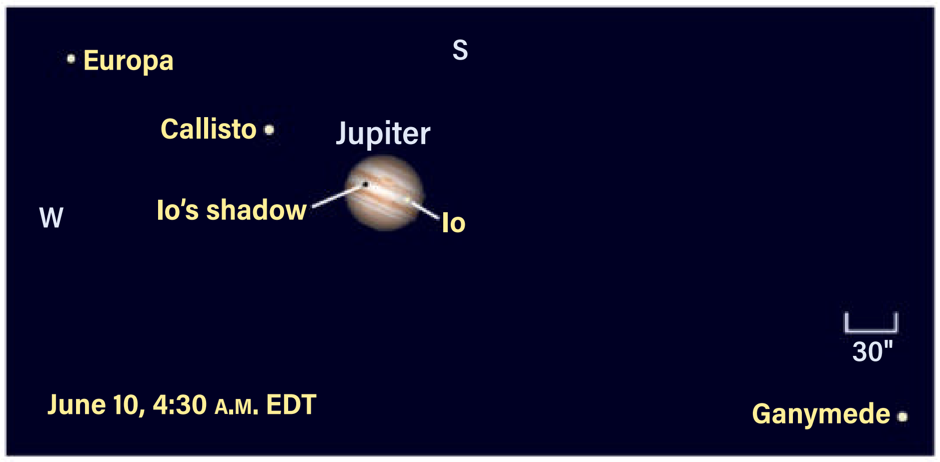


MARS	CERES	JUPITER	SATURN	URANUS	NEPTUNE	PLUTO
June 15	June 15	June 15	June 15	June 15	June 15	June 15
1.8	9.2	–2.5	0.4	5.9	7.8	15.0
4.0"	0.4"	43.1"	17.9"	3.4"	2.3"	0.1"
96%	99%	99%	100%	100%	100%	100%
2.340	3.573	4.574	9.263	20.505	29.890	33.437
1.662	2.873	5.043	9.959	19.750	29.924	34.301
8h17.6m	2h54.3m	22h16.7m	21h01.9m	2h42.0m	23h35.6m	19h53.2m
21°02'	9°52'	–11°42'	–17°37'	15°18'	–3°51'	–22°26'

SKY THIS MONTH — *Continued from page 33*

— Continued from page 33

Sharing space



Io crosses the face of Jupiter the morning of June 10. Both the moon and its shadow share the disk between 4:04 A.M. and 5:04 A.M. EDT.

on June 1 stands 0.7° west of Theta (θ) Capricorni, a 4th-magnitude star better seen once the region is high in the sky in the hour before dawn. Early morning viewers will find the waning gibbous Moon 17° farther east in Aquarius. The Moon returns to Saturn's vicinity June 27, when the ringed planet stands 5° north of our satellite an hour before sunrise.

Saturn's disk reaches a span of 18" by mid-June, while its rings reach 42" wide by June 30. The planet's yellowish disk may show subtle features through a telescope and its best viewed in the hour before dawn, around 4 A.M. local time. Look for white spots, which indicate a new storm erupting. Such storms are rare, but large ones can dominate the planet over the course of just a few weeks. The ring tilt drops below 17° this month, allowing a glimpse at the southern polar region.

Saturn's brightest moon, magnitude 8.6 Titan, is an easy target for small scopes. It lies south of the planet June 8 and 24, and north of Saturn June 16. Fainter Tethys, Dione, and Rhea congregate near Saturn and shine at magnitude 10. Enceladus, near magnitude 12, hugs the outer region of Ring A. Iapetus starts June near 12th magnitude, but progressively brightens to 11th magnitude as it moves toward its June 13 inferior conjunction. By June 30, it's near 10th magnitude and 8.8' due west of Saturn.

Jupiter rises an hour after Saturn and is about 30° high in the southeast June 1 at 4:30 A.M. local time, just as the first signs of twilight paint the sky. It shines at magnitude –2.4 among the dimmer stars of Aquarius the Water-bearer.

Jupiter's eastward progression slows until it reaches a stationary point June 21. The planet has brightened to magnitude –2.6 and stands 8.5° northeast of a waning gibbous Moon the morning of June 28.

Viewing improves during the month and by June 30, when it rises shortly before midnight, Jupiter stands nearly 40° high at 4:30 A.M. local time. This is the highest Jupiter has been in Northern Hemisphere skies for four years. The higher elevation improves its brightness and clarity as light from the planet passes through less of Earth's atmosphere.

Jupiter's disk spans 41" as June begins and grows to a fine 45" wide by month's end. The gas giant is still two months from opposition but offers an outstanding view through telescopes. The main equatorial belts straddle the middle of the planet, while subtle dusky features transit quickly from east to west as Jupiter's fast rotation period carries them across the visible disk. That rotation period varies with latitude but ranges from five to 10 minutes less than 10 hours, so the motion of features is visible with just a few minutes of careful observation.

WHEN TO VIEW THE PLANETS

EVENING SKY
Venus (west)
Mars (west)

MIDNIGHT
Jupiter (east)
Saturn (east)

MORNING SKY
Mercury (east)
Jupiter (south)
Saturn (south)
Uranus (east)
Neptune (southeast)

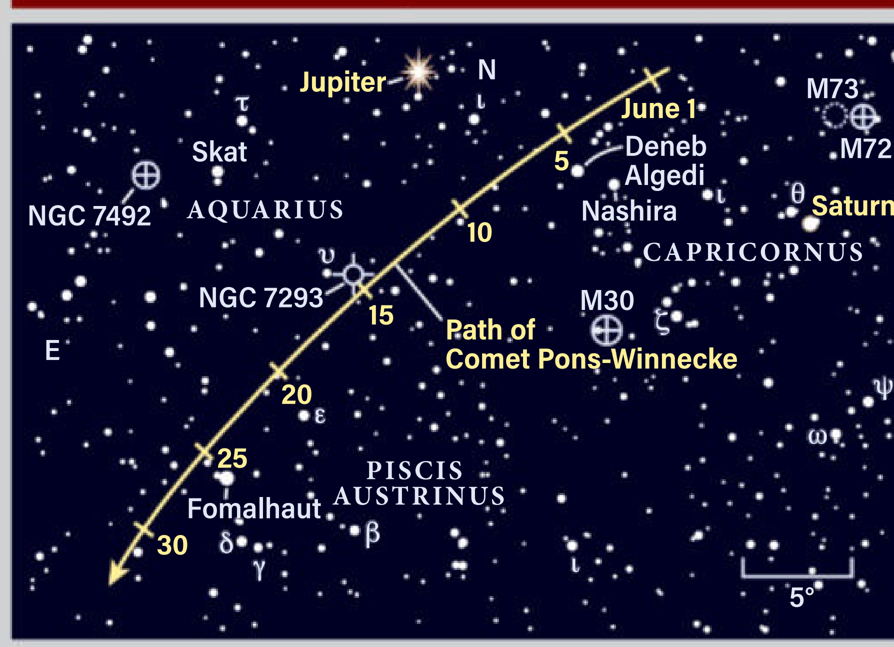
COMET SEARCH | Almost a ringer

THIS IS THE YEAR to add no. 7 to our list of periodic comets, a first for most of us. Discovered over 200 years ago by Jean Louis Pons, Comet 7P/Pons-Winnecke sports a surprisingly short period of 6.4 years. You'd think it would be well known, but Pons-Winnecke is so small that it must be nearby for us to see it well.

The comet's closest approach to Earth occurs June 12, when it comes within 0.44 astronomical unit (1 astronomical unit, or AU, is the average Earth-Sun distance), and astronomers expect it to glow at magnitude 11.5. Back in 1927, it came within 0.04 AU — just 16 lunar distances — and was visible to the unaided eye at magnitude 3.5. Our next decent shot at Pons-Winnecke comes in 2037 (0.27 AU), but 2045 brings us closer (0.21 AU).

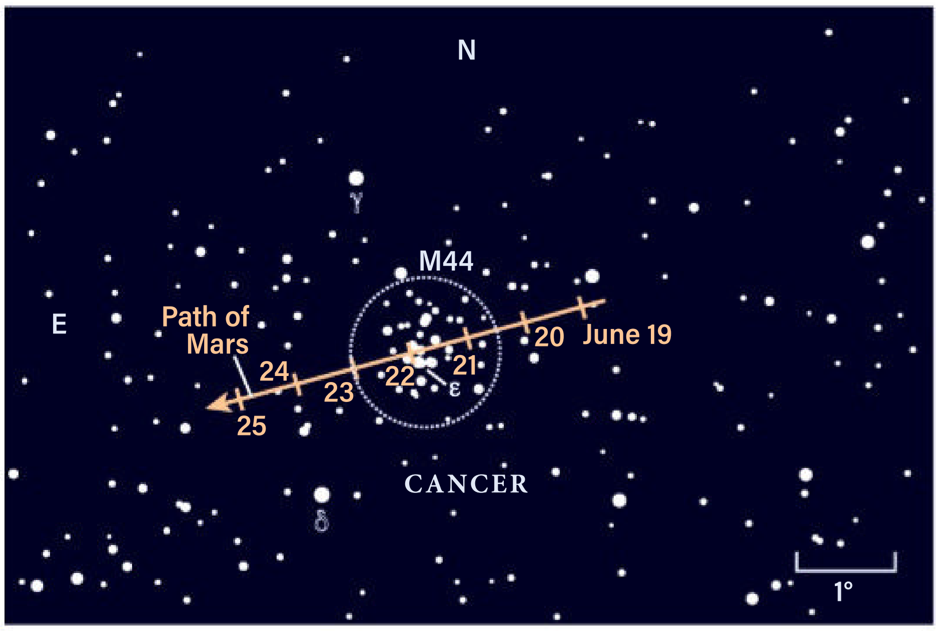
The observing and imaging highlight occurs on the 15th, when Pons-Winnecke sits less than twice the diameter of the Helix Nebula (NGC 7293) to the nebula's southwest. A dark sky and a 6-inch scope are a must, along with the fortitude to search just before dawn breaks and the planning to ensure your equipment is guarded against a soaking dew.

Comet 7P/Pons-Winnecke



Comet Pons-Winnecke is back and comes closest to Earth on June 12. The positions of Jupiter and Saturn are shown on June 15.

Mars meanders through the Manger



Mars passes through the Beehive Cluster (M44) — also known as Praesepe or the Manger — late this month.

Jupiter's four Galilean moons, Io, Europa, Ganymede and Callisto, are also visible most nights. Their changing positions are fun to track.

Neptune is located in northeastern Aquarius and reaches a stationary point June 26. It rises just after 2 A.M. local time June 1, and two hours earlier by June 30. On the 1st, Neptune stands 5.6° east of Phi (ϕ) Aquarii and due south of the Circlet in Pisces. The ice giant's magnitude of 7.8 places it within range of binoculars an hour or two before dawn. Its identity is easy to verify, especially with a good star map. Neptune remains within 7' of a slightly brighter (magnitude 7.2) field star all month, appearing like a double star. Although the planet moves slowly from night to night, its motion relative to this star is easy to notice.

Uranus emerges in the predawn sky and is best found using binoculars in late June, when the planet stands about 20° high as twilight breaks. It lies in Aries, nearly 12° southeast of Hamal, the Ram's brightest star. Uranus picks up a double during the last few days of the month as it comes close to Omicron (ο) Arietis, a field star of similar brightness to the magnitude 5.9 planet. On June 30, the bluish planet stands 11' due north of the star.

Mercury reaches inferior conjunction with the Sun on June 10 and moves west of the Sun in late June. It's too faint to spot in bright twilight until the last week of the month. On June 30, the planet shines at magnitude 1 and is just over 8° east of Aldebaran in Taurus. Look east at 4:30 A.M. local time to find Aldebaran 5° high; over the next half hour, see if you can spot Mercury as it rises while the sky brightens. Observers in the Southern Hemisphere and the tropics have a better view.

Earth's summer solstice occurs June 20 at 11:32 P.M. EDT.

An annular solar eclipse takes place June 10. Annular eclipses occur when the Moon is farther than average from Earth during a total solar eclipse, making our satellite too small to cover the entire solar disk. This leaves a ring of solar photosphere visible along the center line of the eclipse. The eclipse track runs across the extreme northern regions of Canada, Greenland, and the Arctic Ocean, as well as far northeastern Russia.

In Canada, the annular eclipse will be visible starting about 100 miles northeast of Thunder Bay, Ontario. A partial eclipse is already underway at sunrise (about 5:50 A.M. local time). The low altitude of the Sun when annularity begins just after sunrise means a very clear sky is required to see it. The path continues across barren land until it reaches the Hudson Bay at Polar Bear Provincial Park. Eclipse chasers from the cities of Toronto, Montreal, Ottawa, and Quebec can take Route 11 through North Bay, Ontario, and cross into the path of the annular eclipse just beyond the small town of Mattice, Ontario.

Martin Ratcliffe *is a planetarium professional and enjoys observing from Wichita, Kansas.* **Alister Ling**, *who lives in Edmonton, Alberta, is a longtime watcher of the skies.*

LOCATING ASTEROIDS

Heyo Leo trio

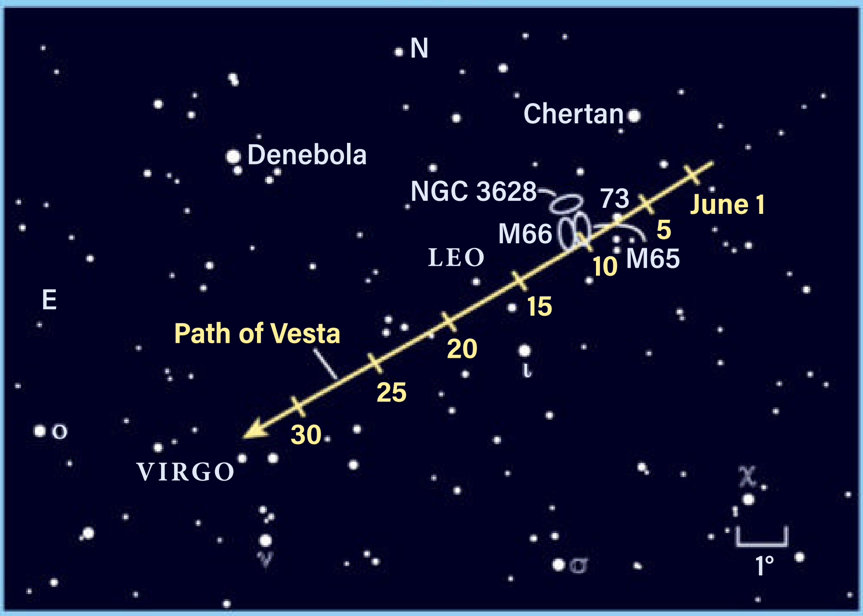
CONTINUING TO DOMINATE the spring and summer asteroid standings, 4 Vesta slowly slips from Leo into Virgo. Shining at magnitude 7.5, this 300-mile-wide space rock might be getting tough for binoculars from the suburbs, but remains easy to locate with a small scope. Look among the bright stars of the Lion's hindquarters and the Maiden's head.

Messier fans are familiar with the bright spiral galaxies M65, M66, and their sidekick NGC 3628, which together form the Leo Triplet. From the 7th to the 13th, Vesta is less than 1° to their south, skimming a mere 7' from 5th-magnitude 73 Leonis on the 7th.

Located toward the outside of the main belt, Vesta moves slowly, giving fewer chances to see it shift during a single session. By a third consecutive night of observing, its 40' displacement will be obvious on your sketch of a distinct starfield. If you have three hours on the 17th or 21st, you could notice the sidestep.

Coincidentally, on the 17th, asteroid 3 Juno lies on the northeast outskirts of globular star cluster M10 in Ophiuchus. Look for its magnitude 10 glow as this nearby world threads through a field of red giants lurking some 14,000 light-years in the distance.

Skirting stars and galaxies



Asteroid Vesta trades the Lion for the Maiden this month, passing the famous Leo Triplet along the way.

It doesn't take a huge telescope to view the beauty of the cosmos. Here's how to make the most out of what you have. BY KEVIN RITSCHEL

BACKYARD ASTRONOMY *with a small scope*

About 10 years ago, I was severely bitten by the aperture bug. I was using large telescopes in rural locations to chase down galaxies, as well as obtain detailed views of brighter objects. And while these scopes did produce memorable results, a big telescope has a serious drawback, other than being a beast to transport: You only see a small portion of the sky at a time.

So, to get a better view of the California Nebula, a notoriously faint and expansive object, I started to employ smaller and smaller telescopes, including 10-inch, 8-inch, and 6-inch, achieving various degrees of success. Almost as a lark, I eventually decided to try my luck with a short-focal-length 3-inch refractor. That little refractor, combined with a 2-inch wide-field eyepiece, 2-inch diagonal, and a Hydrogen-beta (Hβ) filter, produced the best view of the California Nebula I have ever seen. It was not barely there, as usual. It was a pronounced, distinct view that stood out from the background. Thus, I began an astronomical adventure to see what else a 3-inch would reveal under a dark sky.

What can one find with such a modest telescope? Well, it will help you spot most of the Messier catalog and many of the Caldwell objects, as well as a lot of other wonders. Yet, what a 3-inch, wide-field telescope really excels at is fitting big objects and groupings of several objects in one view. For example, the 3-inch f/6.2 (500mm focal length) refractor I have been using recently gives me dependable, exciting views of expansive and faint fuzzies like Barnard's Loop, the Rosette Nebula, and the North America Nebula. It also opens up beautiful panoramas of the open clusters of Cassiopeia, as well as the Sagittarius and Cygnus star clouds.

Let's look at some of the advantages of small telescope observing, and then I'll discuss some of my favorite targets, season by season.

Perks of a small telescope

Wide fields of view: A short-focus telescope gives you a wide field of view. That means you can take in a big chunk of the sky at once. The eyepiece that I use most consistently for survey work with a 3-inch refractor is a 2-inch, 22mm eyepiece with an 82° apparent field of view (AFOV). That translates to a 3.5° true field of view at 23 power — about the same as good wide-field binoculars! And to catch some of the most imaged objects in the sky, you need a large field-of-view. For example, the North America Nebula in Cygnus (NGC 7000 or Caldwell 20) spans about 2° by 1.7° in the sky, while the California Nebula in Perseus (NGC 1499) covers about 2.5°. Plus, having a wide enough field of view allows you to capture some of the darker background sky, making the faint objects you're targeting stand out even more.

Portability: The best amateur telescope in the world will not help you enjoy the sky if it never leaves your garage. Small scopes, sometimes referred to as grab-and-go telescopes, are favorites because they can be used on a whim. You'll be surprised at how often you'll take it out onto your deck or into your backyard, or even toss it in your trunk and drive to a dark-sky site.

Affordability: A short-focus refractor or reflector of 3 to 6 inches in diameter doesn't cost a fortune, which means you could potentially put the money you save toward wide-field eyepieces to use with it. While I have owned 3-, 4-, 5-, and 6-inch extra-low dispersion (ED) refractors, the 2.4- and 3-inch refractors I most often use are the more basic, non-ED designs. I encourage you to go out to a dark site and try looking at the night sky, as you can see lots of neat objects with pretty modest equipment. However, if you really want to chase the big and faint celestial sights, I recommend you to invest in some moderately wide-field eyepieces, narrowband filters, and diagonals.

A modest telescope can help you spot most of the **Messier catalog** and many of the **Caldwell objects,** as well as a lot of other wonders.

This deep exposure brings out many beautiful targets within the familiar constellation Orion the Hunter. The red circle among the passing clouds is Barnard's Loop. The Horsehead Nebula is visible near Orion's famous belt stars. And to the lower left is the Rosette Nebula. Light pollution from the city Chengdu, China, is visible off in the distance. JEFF DAI

The heart of Orion includes Barnard's Loop and several other major nebulae, as seen in this image taken from the photographer's backyard in Montrose, Colorado, on Jan. 14, 2021. Numerous reflection nebulae — illuminated by Rigel, which is located just outside the frame — are also visible near the top. VINCE FARNSWORTH

WINTER TARGETS

OBJECT	TYPE	CONSTELLATION	NOTES
↑ **Barnard's Loop**	Supernova remnant/ emission nebula	Orion	To see this very subtle target within the Orion Molecular Cloud Complex, use the lowest possible power and an Hβ filter. You may need to nudge your telescope slightly while viewing the area to notice how the nebulosity moves in the field.
Witch Head Nebula (IC 2118)	Reflection nebula	Eridanus	This one's a real challenge. Located just west of Rigel in Orion, you need a dark site and transparent skies to see it.
Orion's Belt	Association and emission nebulae	Orion	With a 3-inch refractor, you can easily spot the nearby Flame Nebula, as well as hints of the emission nebula IC 434, which harbors the shadowy Horsehead Nebula. The reflection nebula M78 lies just outside the field to the northeast.
NGC 2174 & NGC 2175	Emission nebula and open star cluster	Orion	Both of these targets are easy to pick out without an Oxygen-III (OIII) filter.
Rosette Nebula	Emission nebula	Monoceros	This celestial sight is also visible without filters, but an OIII filter still enhances the view.

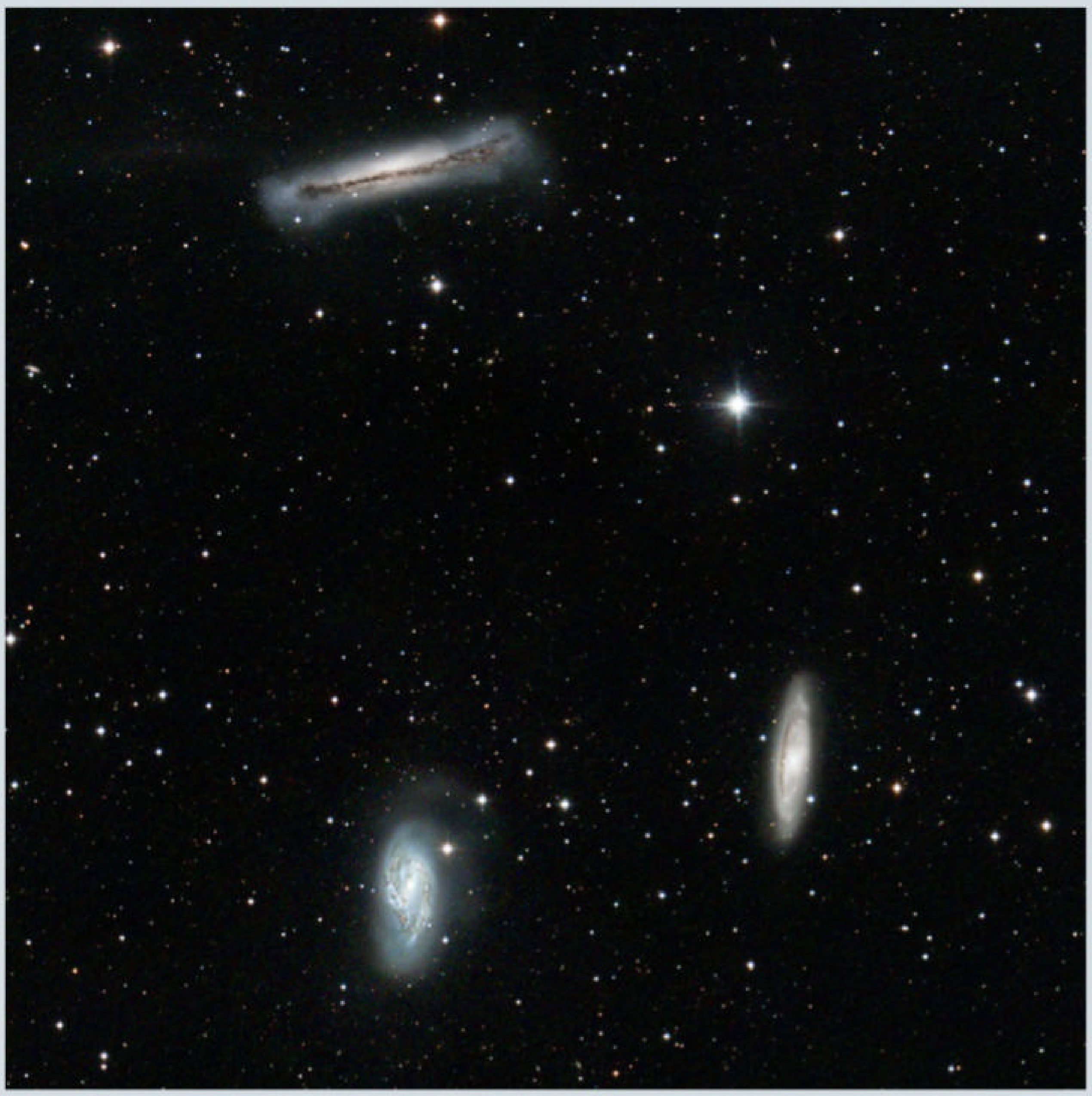
How to make the most of a small scope

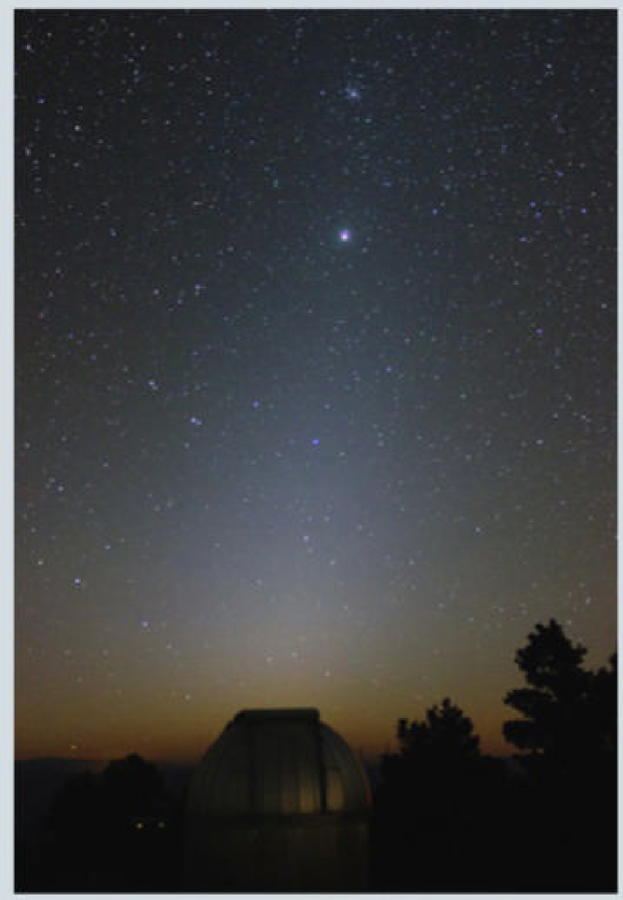
SEEK DARK, TRANSPARENT SKIES. I cannot overemphasize enough how tracking down deep-sky objects with a small scope is far more rewarding if you do it from the darkest, least light-polluted site you can find. Dark skies make the contrast between the object you seek and the surrounding sky much more apparent. There's simply no getting around the fact that urban skies wash out deep-sky objects. But a small, portable telescope also makes for a good travel companion, providing an excuse to venture to spectacular dark-sky sites like national parks.

CONSIDER A STEADY MOUNT. A solid mount for a small, lightweight telescope is relatively cheap to purchase, and it makes it much easier for you to locate and spot the details of your target. I recommend getting a mount with slow-motion controls, if possible, as they allow for quick and easy fine adjustments.

SPRING TARGETS

OBJECT	TYPE	CONSTELLATION	NOTES
M48 (NGC 2548)	Open star cluster	Hydra	From a dark-sky location, you should be able to see this cluster with your naked eye. It is nicely resolved in 2.4- and 3-inch refractors.
M81 (NGC 3031) & M82 (NGC 3034)	Galaxy grouping	Ursa Major	Visible in both 2.4- and 3-inch refractors, this view is one of the grandest galaxy pairings in the sky.
Omega Centauri (NGC 5139)	Globular star cluster	Centaurus	If you live in the lower 48 states or Hawaii, this is one of the most amazing sights in the sky. It's easy to see with 2.4- and 3-inch telescopes. Plus, the peculiar galaxy Centaurus A (NGC 5128) is located about 4.5° north, and even sports a dark lane.
Beehive Cluster (M44, NGC 2632)	Open star cluster	Cancer	This seasonal treat is easy to pick out and fully resolved with the smallest of scopes. You can even see it with your naked eye under very dark skies.
M65 (NGC 3623) & M66 (NGC 3627)	Galaxy grouping	Leo	Can you also pick up hints of a third galaxy nearby, the Hamburger Galaxy (NGC 3628)?





ABOVE: Early on Oct. 2, 2014, the photographer snapped this shot of bright Jupiter with the Beehive Cluster above it. The image also captures zodiacal light, caused by sunlight reflecting off of dust spread throughout the solar system. DALE CUPP

LEFT: The Leo Triplet (M65, M66, NGC 3628) was captured in this shot from the photographer's backyard observatory in Long Island, New York, under Bortle 7/8 skies. DAVID BARNETT

Indeed, I have a fairly robust equatorial mount that I can equip with several scopes at once. And while such a mount may seem like overkill for only a little 3-inch refractor, the excellent handling it provides makes it a breeze to quickly view a lot of different objects during a single night of observing.

DON'T FORGET YOUR FILTER. Narrow-band filters are essential for observing faint-emission nebulae, even from a particularly dark-sky site. You'll be surprised by how well some objects respond to an Oxygen-III (OIII) filter, like the Owl Nebula (M97 or NGC 3587) in Ursa Major or Thor's Helmet (NGC 2359) in Canis Major. Some objects, such as the California Nebula and Barnard's Loop, require an Hβ filter to identify them.

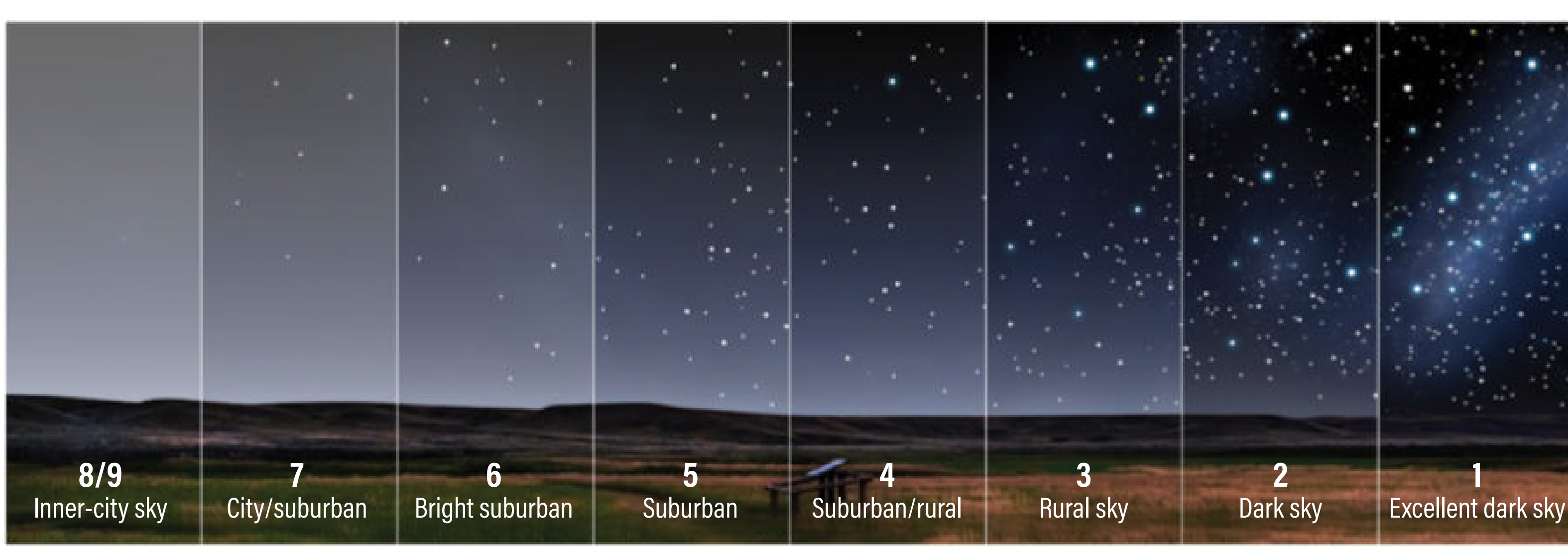
GRAB A WIDE-FIELD EYEPIECE. Getting at least one low-power, 60° to 82° AFOV is essential for your deep-sky kit, at least in my opinion. While a good

ABOVE: The Lagoon (left) and Trifid (right) nebulae are both popular targets in Sagittarius. FABIO DI STEFANO

LEFT: The Eagle (left) and Omega (right) nebulae are shown here using the Hubble Palette. ALISTAIR SYMON

SUMMER TARGETS

OBJECT	TYPE	CONSTELLATION	NOTES
↑ **Eagle & Omega nebulae (M16, M17)**	Emission nebulae panorama	Serpens & Sagittarius	Both 2- and 3-inch refractors capture the Eagle Nebula and Omega Nebula (M16 and M17, respectively) in the same field of view. The Omega Nebula's classic check mark shape is readily apparent in a 3-inch scope.
→↑ **Lagoon & Trifid nebulae (M8, M20)**	Emission nebulae panorama	Sagittarius	As two of the best emission nebulae visible from the Northern Hemisphere, these targets are easily seen in a single field of view with 2- to 3-inch refractors. Many other open and globular clusters speckle the same area of the sky.
Ptolemy's Cluster (M7 or NGC 6745)	Open star cluster	Scorpius	Ptolemy's Cluster is a beautiful, fully resolved grouping of stars that can be seen in both 2- and 3-inch refractors. Look for the globular cluster NGC 6453 on its northwest edge and the dark nebulae B286 and B287 to the south. With a wide enough field of view, you can also catch the Butterfly Cluster (M6), located about 3.5° to the northwest.
M22 (NGC 6656), M28 (NGC 6626), NGC 6638	Globular star cluster panorama	Sagittarius	Look at Lambda (λ) Sagittarii, the star at the top of the Teapot asterism. In the same field, you will easily find two fine globular star clusters, along with a third that's more of a challenge.
North America Nebula (NGC 7000)	Emission nebula	Cygnus	Use your lowest power/widest field-of-view eyepiece and an OIII filter for the best view possible of NGC 7000. The region is about 1° to 2° east-southeast of the bright star Deneb.



THE BORTLE SCALE

The Bortle Scale is one way to measure the darkness of the night sky. It ranges from 1 to 9, with 1 referring to a fully dark sky devoid of light pollution, and 9 corresponding to a heavily light-polluted inner-city sky.

ASTRONOMY: ROEN KELLY

FALL TARGETS

OBJECT	TYPE	CONSTELLATION	NOTES
Barnard's Galaxy (NGC 6822)	Dwarf galaxy	Sagittarius	This target is another real challenge. I have seen Barnard's Galaxy in many other scopes, but in a 3-inch refractor, it appears as a patch of sky that's just slightly brighter than the background.
Pleiades (M45)	Open star cluster	Taurus	At almost 2° wide, the Pleiades (or Seven Sisters) fits nicely in the field of view of both 2- and 3-inch scopes. You should even glimpse the reflection nebulae around the brightest stars; I can usually make out at least two patches.
NGC 253 & NGC 288	Galaxy and globular star cluster pair	Sculptor	Also known as the Silver Dollar Galaxy, the spiral NGC 253 fits into the same field of view as the globular NGC 288 when viewed through both 2- and 3-inch refractors.
California Nebula ➔ ↓	Emission nebula	Perseus	At 2.5° in length, you need a wide-field view to pick up this cosmic tribute to the most populous state in the U.S. Use an Hβ filter to achieve the best results.
The Helix Nebula (NGC 7293) ↓	Planetary nebula	Aquarius	Wow, this is an exceptionally big planetary nebula! It's faint, but easy to see without a narrow band filter; however, an OIII filter makes it (and its dimmer central region) more obvious through a 3-inch scope.

ABOVE: The photographer escaped to the "boot heel" of New Mexico in October 2020 to get this shot of the California Nebula. RICH RICHINS

LEFT: This view of the Helix Nebula was captured from the photographer's backyard in Houston. JEFF SCHILLING

Plössl eyepiece (a design that comes standard with many commercial telescopes) can do the job for many targets, a wide-angle piece makes it far easier to find objects while star-hopping to your targets. An 82° AFOV eyepiece gives a 64 percent wider view than a Plössl eyepiece of the same focal length. Buy or borrow one and experiment, and you'll be sold on the benefits of wide-field eyepieces.

Target your seasonal favorites

Equipped with the knowledge of why small telescopes can be wonderful tools for deep-sky observing, as well as how to get the most out of them, the only thing left to do is to begin exploring. And fortunately, there are countless terrific targets for you to track down — no matter the time of year.

Celestial sights abound under a dark sky. Regardless the size of your scope, there are many incredible views just waiting for you to discover. So don't delay: Grab your small scope, a few basic accoutrements, and start hunting!

Kevin Ritschel *previously worked at major telescope companies and has loved watching the night sky since the third grade.*

Catch a ring of fire ECLIPSE

In a few weeks, the Moon will almost entirely blot out the Sun in a stunning annular eclipse. So, grab your eclipse glasses and get ready.

BY MICHAEL E. BAKICH

Drama, in the form of sublime celestial geometry, is once again coming to our planet. On June 10, 2021, the Sun, the Moon, and Earth will form a straight line in space. While this scenario often produces a total eclipse, this time, the Moon will be too far from us to completely cover the solar disk. The result? People along a narrow path that stretches through Canada, Greenland, and Russia will experience an annular eclipse.

This event derives its name from the Latin *annulus*, meaning "ring." That's because, at mid-eclipse, a ring of the Sun's disk is still visible around the Moon. And that means one important thing for anyone watching: You must use approved solar glasses or solar filters for binoculars or telescopes when observing.

During an annular eclipse, the dark inner shadow of the Moon (the umbra) never reaches Earth. Astronomers, however, call the virtual extension of that shadow the antumbra. If you're beneath the antumbra, you will see annularity. The Moon also has a lighter, outer shadow called the penumbra. Anyone under the penumbra will witness a partial eclipse.

This composite image shows an annular eclipse crossing above the massive Ooty Radio Telescope in southern India on Dec. 26, 2019. At 1,780 feet (540 m) in length, Ooty is the largest single-moving-structure radio telescope in the world. NEELAM & AJAY TALWAR

The nitty-gritty

The Moon's penumbra first touches Earth at 4:12:16 A.M. EDT. The shadow remains in contact with our planet for nearly five hours, finally leaving at 9:11:16 A.M. EDT. The antumbra first touches Earth's surface at 5:49:43 A.M. EDT and its final contact with our planet is at 7:33:45 A.M. EDT. This stretch marks the annular part of the eclipse. The total path length is 4,831 miles (7,775 kilometers). Greatest eclipse occurs at 6:41:51 A.M. EDT at longitude 66°48' West and latitude 80°49' North, 150 miles (241 km) south of Alert, Nunavut, Canada, the northernmost permanently inhabited place on Earth.

The magnitude of this eclipse is 0.9152. This means the Moon's apparent diameter, 29'33.6", will be 91.5 percent that of the Sun's, which will be 31'30.4". At the midpoint of the eclipse, annularity lasts 3 minutes 51 seconds.

LEFT: Annular eclipses may not be as stunning as total solar eclipses, but with the right preparation and cooperative weather, they are quite unlikely to disappoint. AMANJOT SINGH AND SANCHITA ABROL

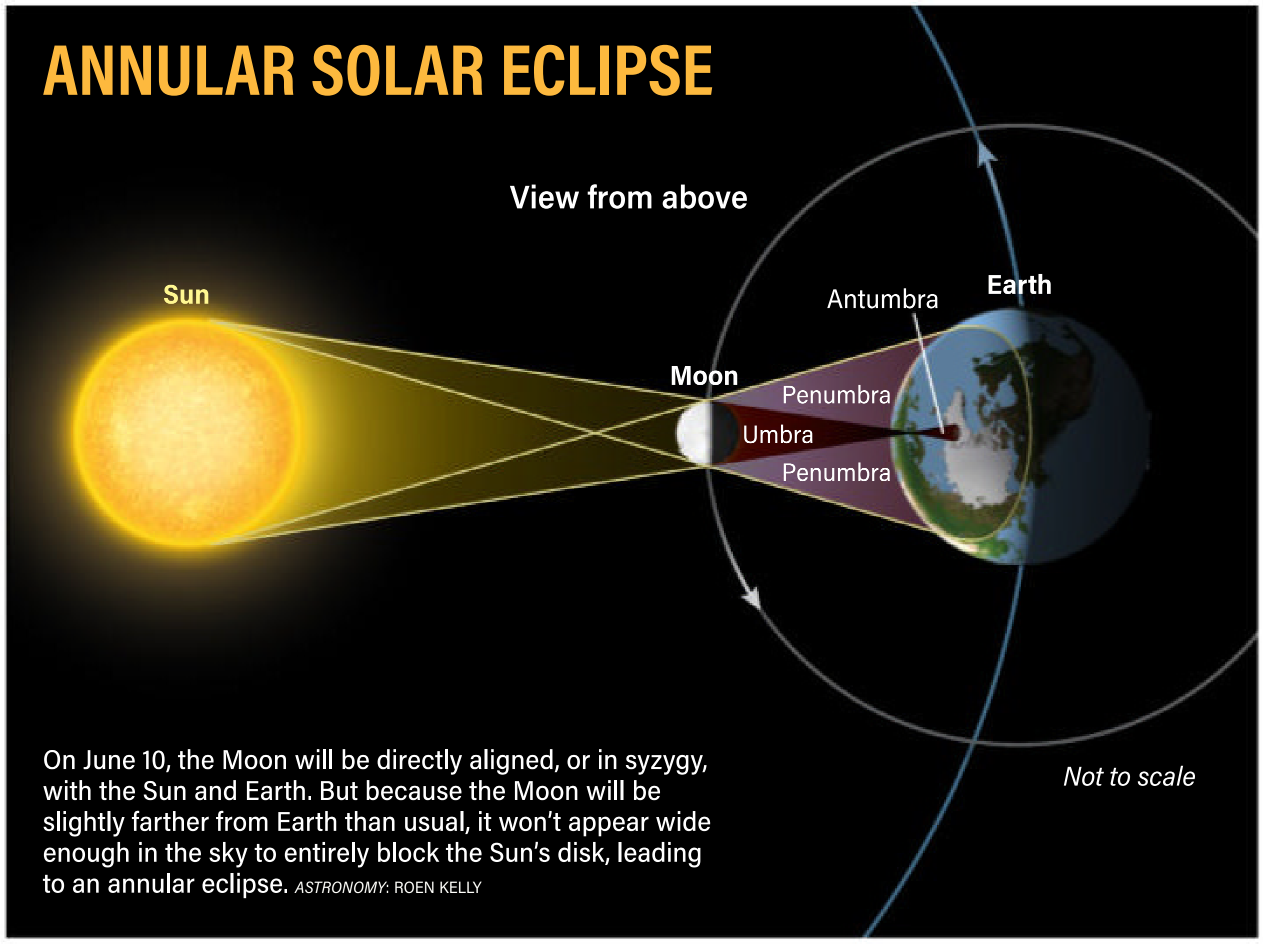
This stunning, fiery ring occurs in the constellation Taurus the Bull, at right ascension 5h15m31s and declination 23°02'37". But it won't be the only sight in the sky: During the eclipse, Venus will lie 20° east of the Sun, shining at magnitude –3.9. The nearby world may be visible a few minutes before maximum annularity, but spotting it will be a difficult task, as it will be low on the horizon. The Sun's maximum altitude during the eclipse will be 23°. If you search for Venus through binoculars, be sure not to sweep the Sun into your field of view.

Canada and Greenland

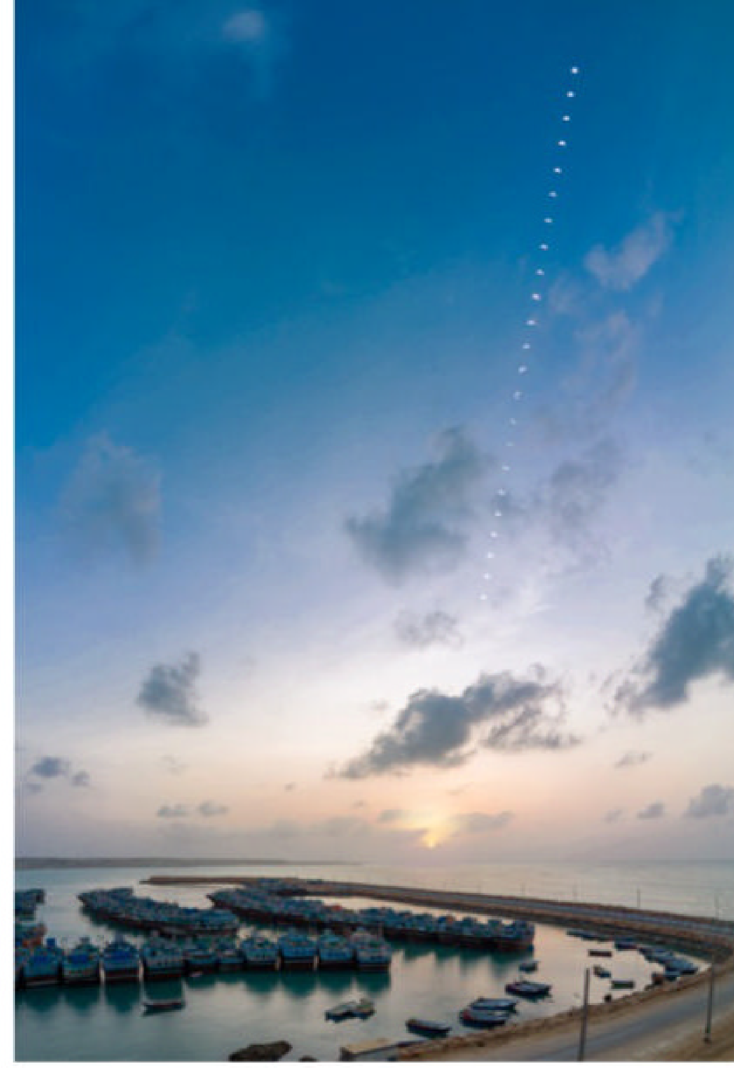
This eclipse begins some 130 miles (210 km) north of Thunder Bay, Ontario (see the map on page 49). Eclipse chasers selecting that region as their observing site might head to Polar Bear Provincial Park, which lies on Hudson Bay. From there, you'll enjoy an unobstructed view (over water) to the north-northeast with the Sun 6° above the horizon. The duration of annularity along the center line will be 3 minutes 33 seconds.

Another vantage point is the northern coast of Akimiski Island in James Bay, Canada. While there, you could visit the Migratory Bird Sanctuary, which occupies the eastern two-thirds of the island. Tourists would sacrifice 10 to 12 seconds of annularity compared to Polar Bear Provincial Park, but they also might spot ringed seals, polar bears, and beluga whales. As the center line crosses the Belcher Islands, the duration of annularity increases a few seconds and the Sun's mid-eclipse altitude climbs to 9°.

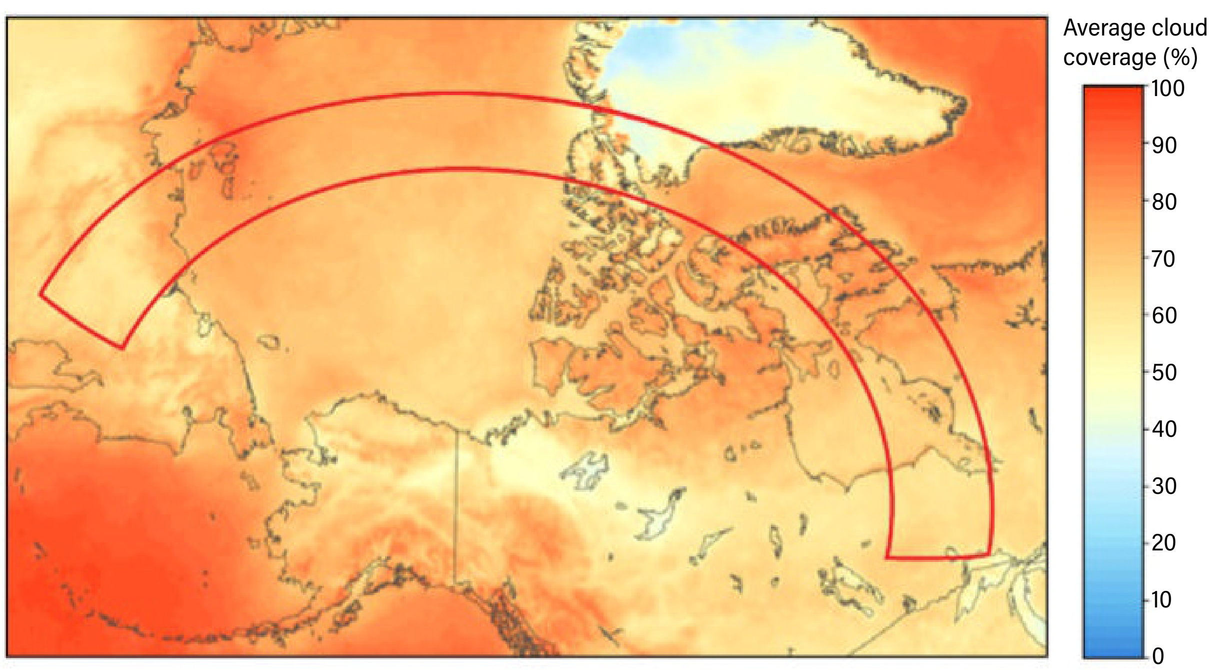
The antumbra next touches the mainland 30 miles (50 km) east of the village of Inukjuak, with 1,800 inhabitants, located at the mouth of Hudson Bay. It continues northward and reaches the Hudson Strait near the northernmost point of Quebec. At water's edge, the Sun stands 15° high at mid-eclipse and annularity lasts 3 minutes 38 seconds. The shadow then crosses more than 800 miles (1,300 km) of Nunavut province. At the coastline of Baffin Bay, annularity begins around 6:19 A.M. EDT. It lasts 3 minutes 43 seconds, with the Sun nearly 21° high



On June 10, the Moon will be directly aligned, or in syzygy, with the Sun and Earth. But because the Moon will be slightly farther from Earth than usual, it won't appear wide enough in the sky to entirely block the Sun's disk, leading to an annular eclipse. *ASTRONOMY*: ROEN KELLY



Taken using a mylar solar filter, the images in this composite show how a solar eclipse on June 21, 2020, evolved between 6 A.M. and 11:30 A.M. above Pasabandar, Iran. HAMED GHADERI



One of the most unpredictable factors in witnessing a beautiful eclipse, whether total, annular, or even lunar, is clouds. This map, based on analyzing historical data, shows the forecast for clouds near the eclipse path in June 2021. JAY ANDERSON

in the east and a perfect watery horizon below it. Unfortunately, weather prospects here are not good. In Canada's boreal forest in June, cloud cover generally ranges from 50 to 60 percent at the beginning of the eclipse track to about 85 percent farther north.

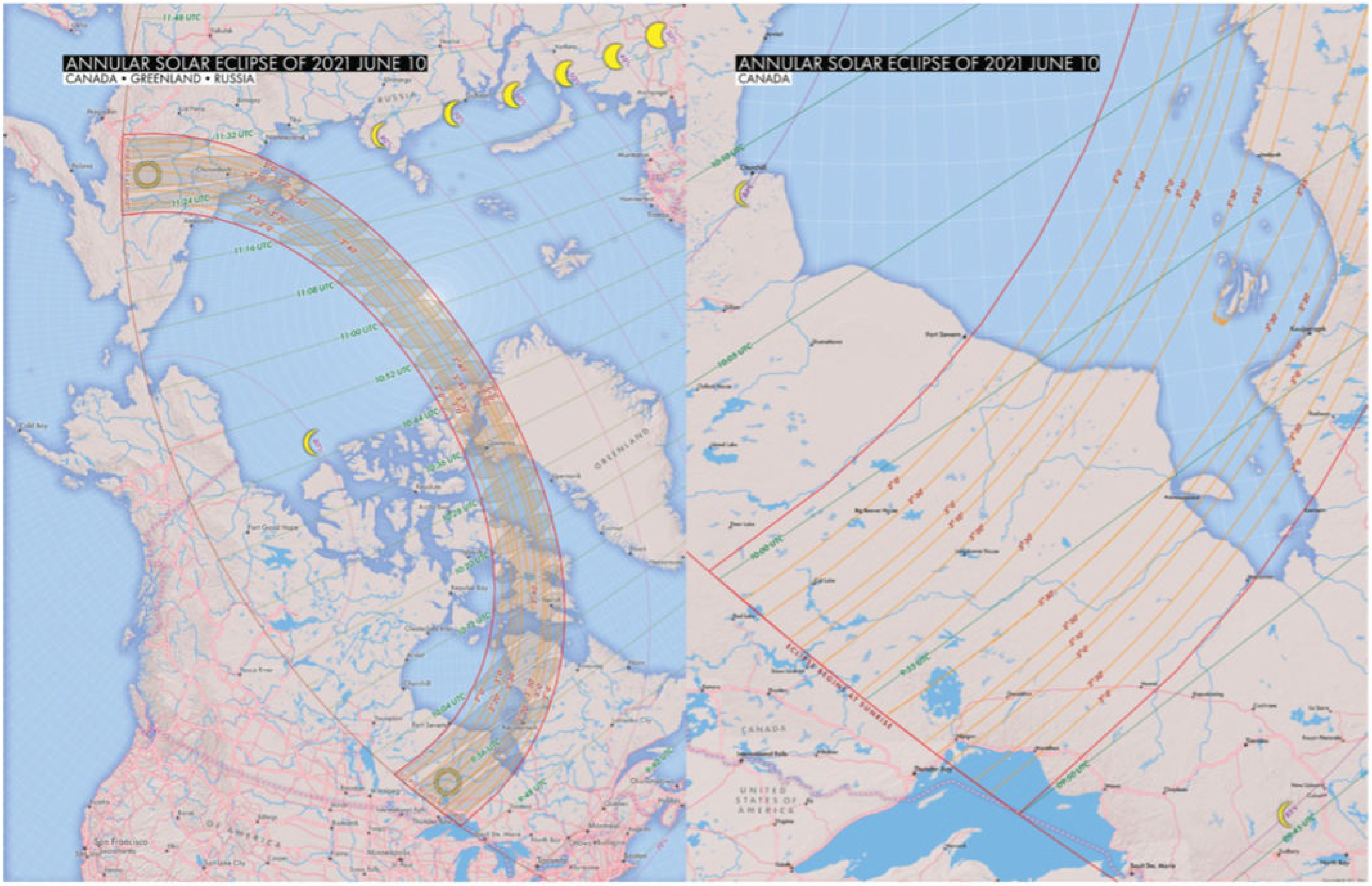
The center line next touches land 20 miles (32 km) west of Savissivik, Greenland. This tiny community of fewer than 100 people is located on the southwestern end of Meteorite Island — a destination that could prove interesting to astronomy buffs. This is where the famous Cape York meteorite fell to Earth more than 10,000 years ago. Its main fragment is the third-largest iron meteorite, weighing nearly 31 tons. This piece, named the Ahnighito fragment, has been on display in the American Museum of Natural History in New York City since 1904.

The Moon's antumbra then treks across the entire northwestern side of Greenland, but it only encounters a half-dozen small villages. The closest to the center line is Qeqertat, which, at around 6:33 A.M. EDT, will experience 3 minutes 43 seconds of annularity with the Sun 23° high in the east. This region boasts the best weather prospects. The cold air there contains much less moisture than elsewhere along the path. One other destination could be Qaanaaq, where annularity lasts 3 minutes 33 seconds and where the mean cloud cover in June is just 39 percent. This is a popular tourist destination for cruise ships and Air Greenland flies into Qaanaaq Airport.

The duration of annularity for this eclipse reaches its maximum in Nares Strait, midway between Greenland and Ellesmere Island, Canada. The antumbra then reenters Canada, where the center line will track for another 220 miles (350 km). For hardy eclipse watchers who want to observe annularity from Canada's northernmost point, head to Cape Columbia for a duration of 3 minutes 42 seconds. From that location, the Sun will stand 23° above the eastern horizon at mid-eclipse. Then, after continuing some 220 miles (350 km) north through the Arctic Ocean, the antumbra leaves Earth's surface — but only for a few minutes.

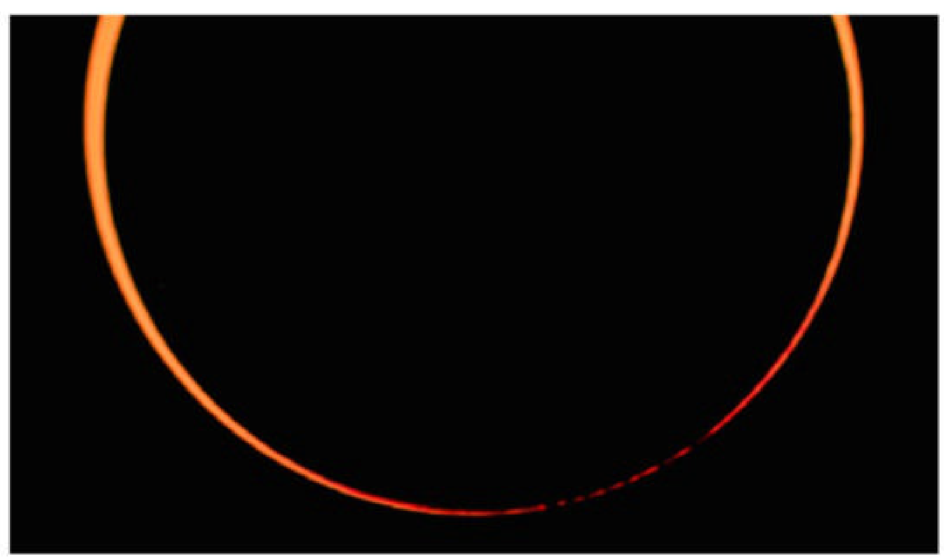
Russia

Because of the geometry of this eclipse — mainly the extremely curved path of the antumbra — after briefly leaving Earth, the shadow will once again touch our planet 1,370 miles (2,200 km) north of the New Siberian Islands in the Laptev



These maps shows the path of the annular eclipse on June 10, 2021, which sees the Moon's shadow trek through both Canada and Greenland, briefly hop off Earth's surface, and then return again to visit Russia. MICHAEL ZEILER

The June 21, 2020, annular eclipse is seen here from the Pacific Ocean side of the Chenggong Fishing Port in Taiwan. LUKE (WEI CHUNG) LU



Bailey's beads, caused by light filtering through the Moon's rugged topography, are evident during the annular eclipse on Dec. 26, 2019. NEELAM & AJAY TALWAR

Sea. From the northern point of Novaya Sibir, annularity lasts 3 minutes 36 seconds, but the Sun's altitude has dropped to 12° at this location.

The center line encounters the mainland of Russia 93 miles (150 km) north of Russkoye Ustye, a village of fewer than 200 people. They will experience 3 minutes 34 seconds of annularity with the Sun 8° high in the northwest. Then, after tracking another 870 miles (1,400 km), the eclipse finally ends its contact with Earth at a point some 155 miles (250 km) north of the Sea of Okhotsk.

Unfortunately, weather prospects throughout Russia are poor, especially when you consider the Sun's low altitude in the sky. Average cloud cover in June ranges from 65 percent to nearly 90 percent. The most favorable locations lie near the end of the eclipse path.

Wherever you choose to travel to observe June's annular eclipse, the best strategy is to arrive a few days early, continually check the local weather report, and stay mobile. If the clouds part, you'll certainly be one of the few people on Earth to glimpse this stunning ring of fire in person. Good luck!

Michael Bakich *is a contributing editor of* Astronomy *who has seen roughly 30 solar eclipses, including 14 total eclipses.*

The sky's best planetary nebulae

These dying stars' final acts put on a great show through amateur scopes. BY MICHAEL E. BAKICH

A STAR LIKE THE SUN SPENDS roughly 10 billion years fusing the hydrogen in its core into helium, releasing energy in the process. But eventually, it exhausts its fuel supply. And when fusion stops providing outward pressure, the pull of gravity shrinks the star's core. This heats it, and the extra energy forces the star's outer layers to expand. Eventually, the star puffs away its atmosphere in pulsations, creating a glowing shell of gas that astronomers call a planetary nebula.

The Milky Way contains more than 3,400 of these objects. They survive for only tens of thousands of years — the blink of an eye on cosmic scales. After that, the shell is too distant for the former core to sufficiently heat and excite its gas. While they exist, however, planetary nebulae make fascinating targets for amateur astronomers. Here are some of my favorites, which I've listed in order of right ascension.

Let's start our tour with the **Bow Tie Nebula** (NGC 40) in Cepheus. This planetary never fails to delight when I show it to others. NGC 40 glows at magnitude 11.5 and measures 37" in diameter. It lies 5.5° south-southeast of the star that marks the head of Cepheus the King, Gamma (γ) Cephei. And even though it's faint, the Bow Tie Nebula looks good through small scopes due to its high surface brightness.

An object's magnitude tells observers how bright it appears. For objects that are not point sources — like planetary nebulae — the integrated magnitude compares all the light from the object to the light of a single star. For NGC 40, then, an integrated magnitude of 11.5 means its total light output equals that of a magnitude 11.5 star.

A 4-inch scope shows NGC 40's oval-shaped disk. Through a 10-inch, the disk shows several bright knots toward the southeast and northwest. Increase the magnification to 200x (if the seeing permits) and look for a dark cavity between the shell and the central star.

Up next is **NGC 246** in Cetus. The easiest way to find it is to first locate two stars: magnitude 4.8 Phi^1 (φ^1) Ceti and magnitude 5.2 Phi^2 (φ^2) Ceti, which form an equilateral triangle with NGC 246. The planetary itself glows at magnitude 10.9 and spans 3.8'.

Use a 6-inch scope at a dark site, and you'll see several stars across NGC 246's face, including an obvious central one. A 12-inch scope reveals a hollow center and a bright, thin rim to the northeast. As with most of these objects, an Oxygen-III (OIII) filter will coax out more detail.

Our first Messier object is the **Little Dumbbell Nebula** (M76) in Perseus. This magnitude 10.1 planetary sits in the far western end of the constellation, near its border with Cassiopeia and

The Medusa Nebula evokes the hideous snakes of its mythological namesake with filaments of gas lit by the same object from whence they came — a dying star puffing away its outer layers. ESO

The Robin's Egg Nebula (NGC 1360) is seen here close to the barred spiral galaxy NGC 1398. DAN CROWSON

The Crystal Ball Nebula (NGC 1514) is thought to be the product of a pair of stars orbiting each other so closely they shared their outer layers, which they puffed into space. KFIR SIMON

Andromeda. You'll find it 1° north of the 4th-magnitude star Phi Persei.

As you'll notice, M76 appears fairly bright because it isn't that large, so its light is relatively concentrated. Its elongated disk measures about 1' across. An 8-inch telescope reveals the two lobes that give the nebula its name. If you use a larger scope, you might even just be able to detect a large halo.

Most planetary nebulae are round — or close to it — but the **Robin's Egg Nebula** (NGC 1360) in Fornax stretches that rule. It appears twice as long (6.5') as it is wide, with the long axis running north to south. The object's magnitude is 9.4, and the northern half glows more brightly than the southern portion. To find NGC 1360, look 5.6° northeast of magnitude 4.0 Alpha (α) Fornacis.

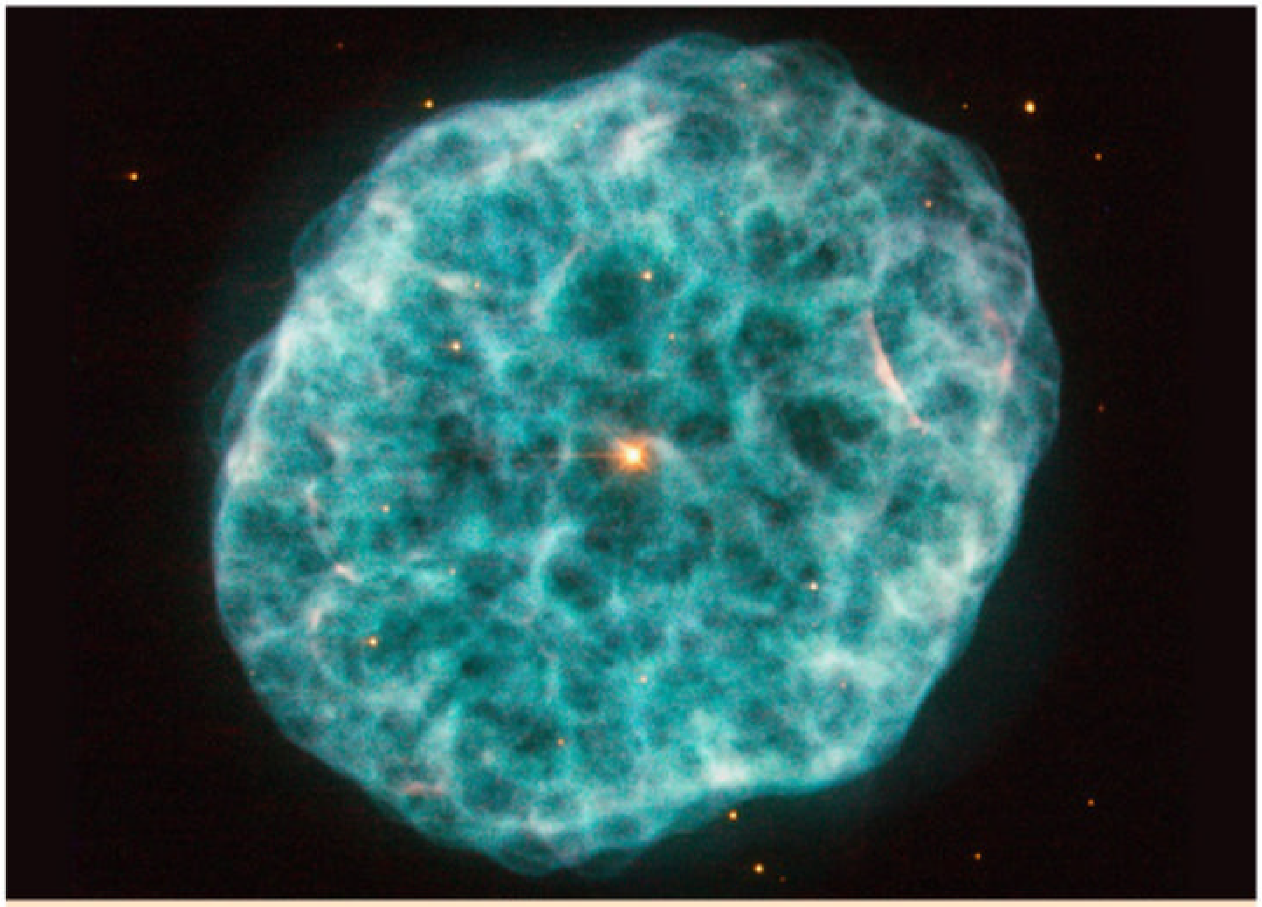
Each lobe of this planetary has a dark lane crossing it. You'll need at least a 12-inch scope to see them, but the dark region in the southern half is the easiest to spot. It stretches from the nebula's southern edge to the 11th-magnitude central star.

Look for our next treat, the **Oyster Nebula** (NGC 1501), 6.9° west of Beta (β) Camelopardalis. It glows at magnitude 11.5 and measures 52" across.

A 10-inch telescope shows a circular disk, but larger scopes and high powers will reveal an oval shape oriented east to west. The Oyster's magnitude 14 central star is easier to see than that number implies. The stellar pearl peeks through a slightly darker core that suggests the presence of a thick ring structure. It may even appear patchy, with several small dark areas visible.

Our next target, the **Crystal Ball Nebula** (NGC 1514) in Taurus, lies 3.4° east-southeast of Atik (Zeta [ζ] Persei). Through an 8-inch telescope at 200x, use a nebula filter to see a magnitude 10.9 round haze that measures 1.9' across — big for a planetary. This object is definitely brighter along its rim. The magnitude 9.4 central star can be a bit distracting, but an OIII filter should dim it to manageable levels. If you still have trouble spotting the star, try increasing the magnification to 150x or beyond.

Now head south into Eridanus for **Cleopatra's Eye** (NGC 1535). It glows at magnitude 9.6 with a diameter of 18".



The pearl of a star that lies at the heart of the Oyster Nebula (NGC 1501) is a variable star — a rarity for a planetary nebula. It pulsates and changes brightness on a period of roughly half an hour. ESA/HUBBLE & NASA; ACKNOWLEDGEMENT: MARC CANALE

The Lion Nebula (NGC 2392), as seen in this Hubble Space Telescope image, sports a magnificent mane made of gas filaments a light-year long — an unusual feature for a planetary nebula. NASA/ANDREW FRUCHTER (STSCI)

NGC 2438 appears situated within the open cluster M46 on the sky. However, it is likely not a member of the cluster, as it has a significantly different radial velocity. MADHUP RATHI

You'll find it 4° east-northeast of Zaurak (Gamma Eridani).

Through a 6-inch scope, NGC 1535 has a sharply defined disk surrounded by a faint envelope. A 10-inch scope will let you see some of the Eye's color. Crank the magnification past 300x, and you'll observe a dark hollow around the central star. You should be able to detect the boundary between the inner disk and the fainter outer shell.

For our next object, head north and a bit east. It's the **Double Bubble Nebula**, also known as NGC 2371 and NGC 2372, a double-lobed planetary that glows at magnitude 11.3. It lies 1.7° north of Iota (ι) Geminorum. Use at least an 8-inch scope, or its details may elude you.

When hunting the Double Bubble, use low power. This object isn't small. It measures 54" by 35". An OIII filter will help. If the seeing is good, use a power of 200x or more and try to spot a brightness difference between the two lobes.

Another worthy target in Gemini is the **Medusa Nebula** (Abell 21). It glows at magnitude 10.3, but it spreads out its light in a circle measuring 10.3' across. Look for it 5° north of Gomeisa (Beta Canis Minoris).

This target can be tough to spot through an 8-inch telescope unless your sky conditions are ideal. Expect to see a faint arc with lots of dark gaps. Areas on the northern and southern ends glow brightest.

Stay in Gemini for the **Lion Nebula** (NGC 2392), which you'll find 2.4° east-southeast of magnitude 3.5 Delta (δ) Geminorum. It glows at magnitude 9.2 and measures 15" across, with a double-shelled appearance. The inner shell appears bright with a mottled texture, and a dark ring separates it from the outer shell. When you look at it, does it remind you of a feline face surrounded by a majestic mane?

With a 10-inch or larger scope, details will emerge. Crank up the power until the seeing breaks down. You'll easily spot the planetary's 10th-magnitude central star.

Our next target, **NGC 2438**, is an easy catch. It lies in Puppis, within the boundaries of the bright open cluster M46. The planetary itself has a magnitude of 11 and a diameter of 1.1'. It sits 7' north of the cluster's center. Use a 10-inch telescope and high magnification, and you may detect the planetary's doughnutlike appearance. Several stars lie within the doughnut's boundary, but none are the object's central star, which is a faint magnitude 17.7.

Now head due east to a point not quite 2° south of Mu (μ) Hydrae for one of my all-time favorite deep-sky objects: the **Ghost of Jupiter** (NGC 3242). Despite its name, its color actually makes it look more like Uranus or Neptune.

At low magnification through a 6-inch scope, you'll see the Ghost's magnitude 7.8 pale, blue-green disk, which spans 16". Through larger scopes and at powers in excess of 200x, the interior appears oval, like an eye or a gridiron football. The inner 10" looks hollow, except for the dim central star. A tough-to-see shell 40" across surrounds the eye. To spot it, you'll need a 12-inch or larger scope, a power of about 100x, and an OIII filter.

One of the best springtime planetaries is the **Owl Nebula** (M97) in Ursa Major, which lies 2.3° southeast of Merak (Beta Ursae Majoris). This magnitude 9.9 object has a diameter of 3.2', so its surface brightness is low. It looks like an owl's face because of the two dark areas in its disk. Each "eye" is slightly less than 1' across and the northwestern one appears a bit darker.

The best views come through an OIII filter and a magnification around 100x. If you view through a 10-inch or larger scope, you'll see the eyes are not equal in size. If your sky is dark, you may also see the disk's outer 10 percent as a faint ring.

The Butterfly Nebula (NGC 6302) is lit across its 3-light-year wingspan by an extremely hot central star with a surface temperature of 450,000 degrees Fahrenheit (250,000 degrees Celsius). However, it was shrouded by so much dust that it was not detected until Hubble was upgraded in 2009. NASA, ESA, AND THE HUBBLE SM4 ERO TEAM

Next up is the **Turtle Nebula** (NGC 6210) in Hercules. It glows at magnitude 8.8 and spans 14". You'll find it 4° northeast of Kornephoros (Beta Herculis). Even through a small telescope, you can easily identify this planetary's light blue, turtle-shaped disk. And while you'll see it right away, it's so bright that you may miss the magnitude 12.5 central star. Through the largest amateur instruments at high magnification, you'll notice NGC 6210 is ever-so-slightly oval in an east-west orientation.

Next, head south to Scorpius for the **Butterfly Nebula** (NGC 6302). You'll find this magnitude 9.6 object 3.9° west of Shaula (Lambda [λ] Scorpii). It's named for its insectlike shape and is one of the brightest and most massive planetary nebulae known.

Through a 6-inch scope, the Butterfly appears like a galaxy four times as long as it is wide (50" by 13"), stretched out east to west. This bipolar nature is apparent at magnifications above 150x. Look for an extension with a tapered end on the western side. Then, try to spot the faint "arm" on the east.

Our next object is a wonderful planetary nebula you'll find just a bit more than 5° east-northeast of Zeta Draconis. Through telescopes as small as 4 inches in aperture, the **Cat's Eye Nebula** (NGC 6543) can look blue, blue-green, greenish-blue, or green, depending on your eyes' color sensitivity. The color is apparent because the Cat's Eye is relatively bright (magnitude 8.1) and spans 18".

Use a magnification of 200x in an 8-inch telescope, and you'll see some hazy spiral structure around the nebula's bright central star. A faint shell 5' across surrounds NGC 6543. This halo contains more mass than the core, and past observers misidentified a bright part of the halo as a galaxy. It even carries its own designation — IC 4677.

Now head south to Ophiuchus to enjoy the **Emerald Nebula** (NGC 6572), a relatively bright (magnitude 8.1) object that any scope will reveal. It sits 2.2° south-southeast of 71 Ophiuchi. Although it's small, only 18" across, it has a high surface brightness. Plus, it's colorful.

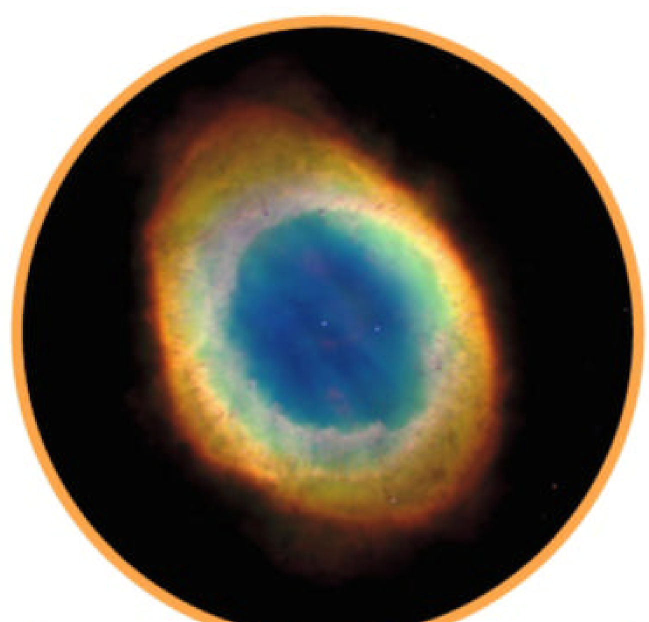
Through an 8-inch telescope, you'll see the Emerald's oval shape. A small but bright central region also appears. To pull out the color, I suggest keeping the magnification low, but I've had good results from 100x to 400x through a 12-inch scope.

Our next object, the **Ring Nebula** (M57) in Lyra, is a great target for small telescopes. It glows at magnitude 8.8 and spans 1.2'. Through a 4-inch scope, you'll see the Ring as a pale gray ball. Cranking the power beyond 100x, you'll see that the outer edge of the ball looks denser than the center. This gives M57 a distinctive smoke ring appearance.

To find it, locate Beta and Gamma Lyrae, the two stars at the end of the parallelogram farthest from Vega. The Ring lies roughly midway between them.

Now move to Aquila and point your telescope 3.8° north-northwest of Delta Aqilae to observe **NGC 6781**. It glows softly at magnitude 11.4 and measures 1.8' across.

Through a 6-inch scope at 100x, NGC 6781 stands out well against a rich, star-filled background. The disk appears soft,



In 1998, when the Hubble Space Telescope team began using discretionary time to take stunning images mainly intended for public consumption, they chose the Ring Nebula (M57) as their first target, producing this image. THE HUBBLE HERITAGE TEAM (AURA/STSCI/NASA)

The Helix Nebula (NGC 7293) glows spectacularly in this image from the La Silla Observatory. At only 700 light-years away, it is a quarter the size of the Full Moon on the sky. The small blobs — called cometary knots — along the inside of the ring are each the size of our solar system. ESO

The Blue Snowball (NGC 7662) has a complex, layered structure. The photographer used OIII and Hydrogen-alpha filters in addition to RGB data to construct this image with a total exposure of 33.4 hours. DOUGLAS J. STRUBLE

irregular, and oval-shaped with a slightly darker center. If the seeing at your observing site is good, look for small, dark blotches over NGC 6781's face.

Our next treat, the **Little Gem** (NGC 6818), sits in a region with no bright stars near Sagittarius' northern border with Aquila. Look for this planetary 9° due west of Beta Capricorni. NGC 6818 glows at magnitude 9.3 and measures 48" across from north to south and a bit less from east to west. The greenish-blue color most observers see appears best at around 100x. However, at magnifications higher than this, you should spot the Gem's ever-so-slightly darker inner half.

Now head north to Cygnus for a fun object to show others at star parties. Through 8-inch and smaller scopes, the **Blinking Planetary Nebula** (NGC 6826) appears to flash when viewed with direct, and then averted, vision. It glows at magnitude 8.8 and spans 25". Look for it 0.5° east of 6th-magnitude 16 Cygni.

From a dark site, I've used a 6-inch telescope at about 100x to make this object blink. Looking at it directly, you'll easily spot the 11th-magnitude central star, but the nebula fades from view. Look a bit to the side (averted vision), and the nebula pops back into sight, swamping the star's light.

For our next treat, move slightly south into the constellation Vulpecula. There, you'll find the **Dumbbell Nebula** (M27), one of the finest planetaries of all. It glows relatively brightly at magnitude 7.3 and spans a whopping 5.8'. The easiest way to find it is to head 3° north from Gamma Sagittae, the star at the tip of the Archer's arrow. Small scopes show two bright regions and several stars superimposed on M27's face. Crank up the power, and the Dumbbell's high surface brightness will reward you.

Our next two targets lie in Aquarius. First is the **Saturn Nebula** (NGC 7009), which glows at magnitude 8.3. You'll find it slightly more than 1° west of Nu (ν) Aquarii.

Through an 8-inch or larger telescope, view NGC 7009 with magnifications above 200x. Its oval disk measures 25" through its long axis. The ringlike extensions that give the nebula its name protrude on each side another 15". At the ends of those protrusions are fainter bulbs, but you'll need at least a 12-inch scope to pick them out. What color do you see in the Saturn Nebula? Whether you see it as mostly blue or mostly green depends only on your color perception.

The second treat the Water-bearer offers is the **Helix Nebula** (NGC 7293). You'll find this great object 1.2° west of Upsilon (υ) Aquarii. The Helix is one of the brightest hard-to-see objects in the sky. Although its total light output nearly reaches 7th magnitude, its diameter is 13', so its surface brightness is disappointingly low. For best results, use binoculars that provide 7x to 15x magnification and have front lenses larger than 50 millimeters.

Through 12-inch and larger scopes with an OIII filter, you'll see bright and dark regions in the ring. The northern and southern edges seem slightly brighter.

Our final target — one of my favorites — is the **Blue Snowball** (NGC 7662) in Andromeda. It glows at magnitude 8.3 and spans 12". Through an 8-inch scope, the Snowball is a small, evenly illuminated disk. Crank up the power and you'll see the nebula's rich inner structure. Look for a bright ring around NGC 7662's hollow center. Then try to spot the fainter shell that surrounds that ring. The ring is brightest to the northeast and southwest.

As you'll quickly see by going through this list, planetary nebulae each have unique features. Pick your favorites and share them with your friends at the next star party. Good luck!

Michael E. Bakich *is a contributing editor of* Astronomy.

Non-urban observin'

City slickers, rejoice: You have options.

An observer at the 2015 Texas Star Party aims his telescope at a target within the Milky Way, which is clearly visible in this single-exposure image taken at a dark-sky site.
ALAN DYER

BY GLENN CHAPLE
Glenn has been an avid observer since a friend showed him Saturn through a small backyard scope in 1963.

Last month, I defined an observatory as nothing more than the place — temporary or permanent — where you set up your telescope for an evening of stargazing. Such a site can be as sophisticated as a state-of-the-art domed structure or as basic as an open spot on a grassy surface. Ideally, it should be situated on your property to eliminate the bother of lugging your scope and gear to a comfortable, remote, and safe setting. But what are your options if you live in an area where backyard astronomy isn't practical, say in a severely light-polluted urban environment?

Short of moving or acquiring an off-property observing site, a good tactic is to contact your local astronomy club for info on accessible locations nearby. There's at least one astronomy club in virtually every major metropolis; to find one near you, go to our website, Astronomy.com, hover over the "Community" tab, and click "Groups." A filtering option allows you to narrow your choices by category or country/state. (Note to astronomy club officers: If your club doesn't appear on our list, take a few minutes and use the "Add Your Group" button to make sure it's on the site. Otherwise, you could be losing potential members!) Many metropolitan astronomy clubs have access to observing sites located in the countryside surrounding their cities. Use of such a facility may require club membership, but the typical annual fees range from about $25 to $50 — which is obviously still a lot cheaper than having to purchase land.

It doesn't matter if they're scrubby pines, stately elms, or concrete skyscrapers, tall objects can obscure anyone's window to the night sky.

Rural stargazers like myself don't have to struggle with extremely restricted space and excessive ambient light like our city-dwelling counterparts do, but we do deal with plenty of trees. And it doesn't matter if they're scrubby pines, stately elms, or concrete skyscrapers, tall objects can obscure anyone's window to the night sky. That's why you need to always plan around them — whether you're in the country or in the asphalt jungle.

For example, the historic Jupiter/Saturn conjunction

this past December was bright enough to be seen from midcity locations, yet I couldn't even glimpse it from my backyard in rural north-central Massachusetts. During the duo's brief period of visibility after sunset, the planets were hiding behind tall pine trees to the southwest. Fortunately, several days prior to the event, I drove around town until I found an area near a high school athletic field that afforded a wide-open view of the event. And this brings me to my next point: Whatever your open-sky location of choice, be sure to get permission from the landowner if it's private property or the local authorities if it's a public space.

But what about catching an astronomical event only visible from a specific area, like a total solar eclipse? Unless you're lucky enough to live near the region of best visibility, you'll have no choice but to pack an "observatory-away-from-home" kit, including astro equipment, toiletries, and perhaps even your laptop. Fortunately, total eclipses attract universal attention, and you can sign up for organized eclipse expeditions that secure your ideal observing site and make your travel plans for you.

So, remember: Just because the city lights aren't conducive to cosmic sights doesn't mean you have to miss out on the fun. With a little effort and planning, even urban observers can enjoy the night sky.

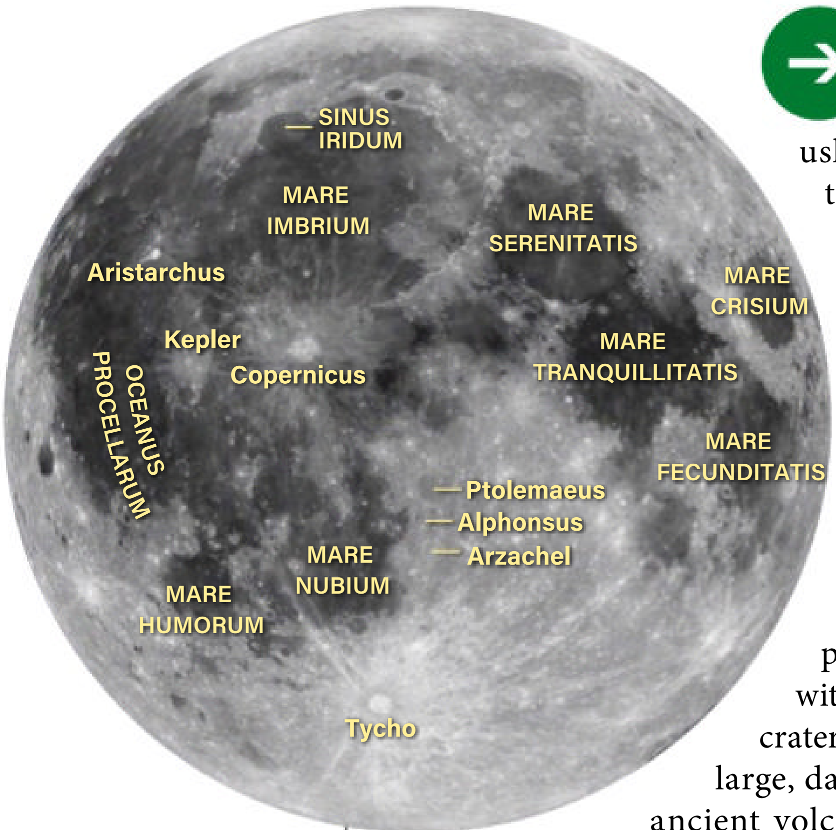
Questions, comments, or suggestions? Email me at gchaple@hotmail.com. Next month: Hunting the Fox! Clear skies!

BROWSE THE "OBSERVING BASICS" ARCHIVE AT **www.Astronomy.com/Chaple**

The Milky Way stretches across the sky in southern New Mexico during a monthly stargazing session co-hosted by City of Rocks State Park and the Silver City Astronomy Club on Nov. 22, 2014. The faint glow of zodiacal light — caused by sunlight reflecting off dust in the inner solar system — is visible above the western horizon to the left. ALAN DYER

A June honeymoon

Short nights are perfect for studying our celestial neighbor.



Explore the Moon's seas and craters this month. NASA/GODDARD SPACE FLIGHT CENTER/ARIZONA STATE UNIVERSITY

BY PHIL HARRINGTON
Phil is a longtime contributor to Astronomy *and the author of many books.*

Dark skies are in short supply during June, as we usher in summer and the shortest nights of the year. So rather than focus on what we don't have, let's look at what we do.

Our Moon is visible long before the Sun sets, after it rises, and even in broad daylight, depending on the phase. It is decorated with a number of impact craters and lunar maria — large, dark plains formed by ancient volcanic activity. Early astronomers once mistook these locations for seas (hence the Latin name *maria*).

Let's begin with New Moon, which occurs June 10. While you won't see the Moon that night, you can see it the night after, as the young waxing crescent lies just above the horizon, bathed in the deepening twilight glow. It's a beautiful sight through binoculars — especially one night later, when Venus appears to its south.

Three nights after New Moon, **Mare Crisium** comes into full view. This large, oval plane measures 270 by 350 miles (435 by 560 kilometers), with the long dimension running east-west. However, its long axis appears to extend north-south, an illusion caused by the Moon's curvature.

Our satellite is a beautiful sight through binoculars.

Five nights after New Moon, dawn has crossed **Mare Fecunditatis** and **Mare Tranquillitatis**. It was along the southwestern edge (southeast in our sky) of the latter that Apollo 11 landed 52 years ago next month. As you look its way, hear in your mind the immortal words of mission commander Neil Armstrong as he took "one small step for [a] man, one giant leap for mankind."

Mare Tranquillitatis flows northward into **Mare Serenitatis**. The last mission to the Moon, Apollo 17, landed near its eastern "shore" in November 1972.

First Quarter begins to cast light on **Mare Imbrium**. The eastern limit of Mare Imbrium is marked by the Apennine Mountains, which curve into the terminator's darkness.

It is usually best to search for individual craters when they lie near the terminator, since the shadowing makes them easier to identify. Can you spot the north-to-south trio of **Ptolemaeus**, **Alphonsus**, and **Arzachel** along the First Quarter terminator? Ptolemaeus is the largest of the three, spanning 95 miles (153 km). Alphonsus is 73 miles (119 km) across, while Arzachel measures 60 miles (96 km).

The Moon's southern hemisphere is cluttered with so many craters that it is hard to distinguish individuals through binoculars. Two, however, stand out. Sunrise on day eight of the lunar cycle sheds light on **Clavius**, the second-largest crater on the Moon's nearside. This monstrous impact feature appears oval-shaped from Earth, but that's only because of the lunar globe's curvature. It's actually circular, 144 miles (231 km) in diameter.

This same night, a spark is struck to the lower right of Clavius as the crater **Tycho** enjoys sunrise. As the phases progress toward Full Moon, watch Tycho's brilliant system of rays turn that spark into a conflagration of bright beams of ejecta spraying northward across the Moon.

As the waxing gibbous phases advance, sunlight uncovers the rest of Mare Imbrium, including a dent along its northern edge known as **Sinus Iridum** or the Bay of Rainbows. Sinus Iridum is the remains of a large crater whose south wall was subsequently breached by lava from Mare Imbrium. The bay's "mouth" spans 155 miles (249 km). As the days march onward, the terminator reveals **Mare Humorum**, **Mare Nubium**, and finally the largest mare of all, **Oceanus Procellarum**, which has three brilliant craters. At nearly twice the size of Alaska, the Ocean of Storms is the only lunar maria to earn the title "ocean."

The first of Oceanus Procellarum's craters to see sunlight is **Copernicus**, famous for its dazzling rays that burst into view against the darker surroundings. By Full Moon, the rays are visible without any optical aid at all. To its west (our east) sits the crater **Kepler**. While Copernicus measures 58 miles (93 km) across, Kepler is just one-third as large. Yet Kepler is one of the most prominent craters on the Moon, thanks to its bright ray pattern. It may remind you of a miniature Copernicus. The third bright crater adorning Oceanus Procellarum is **Aristarchus**. Like Copernicus and Kepler, Aristarchus is highlighted by a magnificent system of rays extending from its rim into the mare.

And that brings us to Full Moon. As our satellite continues in its orbit, the waning phases that follow turn the terminator into the sunset line. It's fun to stay up late or rise early to watch each of the features listed here say goodnight as the Sun drops below their western horizon.

Questions, comments? Contact me through my website, philharrington.net. Until next month, remember that two eyes are better than one.

BROWSE THE "BINOCULAR UNIVERSE" ARCHIVE AT **www.Astronomy.com/Harrington**

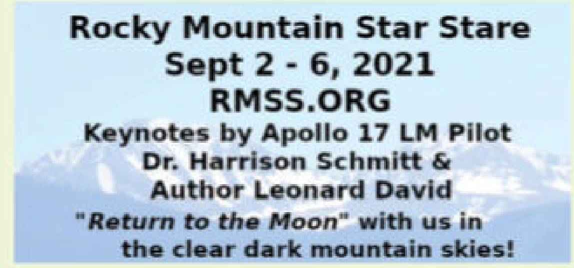
INDEX *of* ADVERTISERS

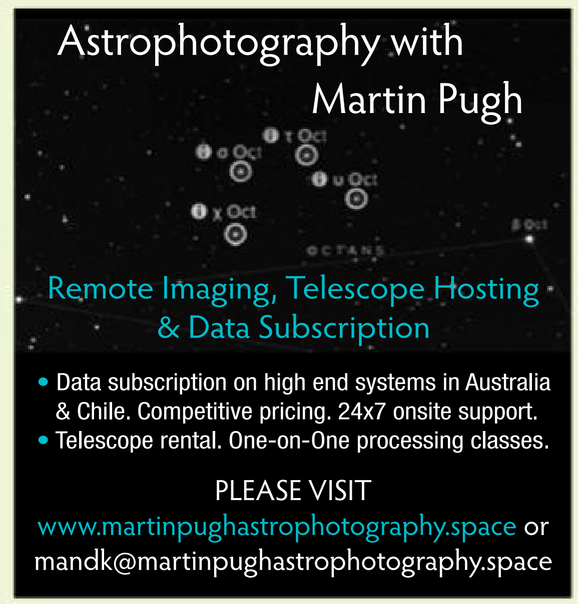
The Advertiser Index is provided as a service to *Astronomy* magazine readers. The magazine is not responsible for omissions or for typographical errors in names or page numbers.

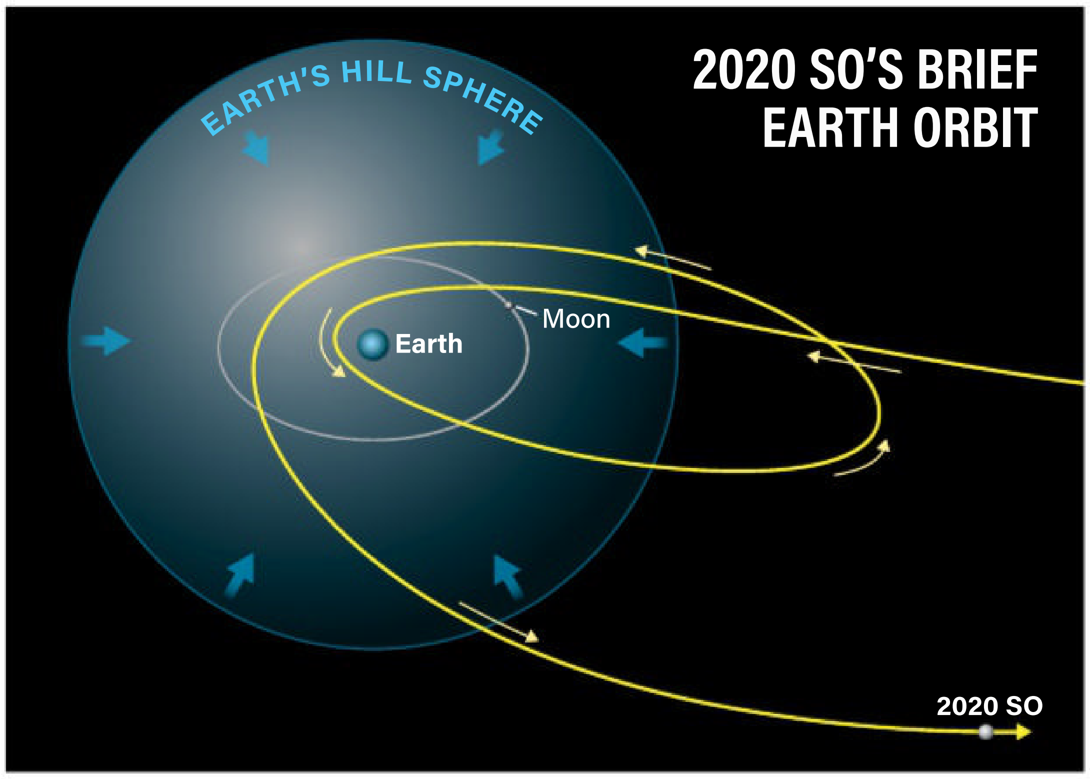
Each monthly issue of *Astronomy* brings you:

- Spectacular photography
- Expert observing tips
- Readable, user-friendly articles
- Timely science reporting
- Monthly star maps
- and much more!

Astronomy.com







In November 2020, Earth temporarily recaptured a rocket booster originally launched in the 1960s. After a few months orbiting our planet, 2020 SO returned to its orbit around the Sun. *ASTRONOMY*: ROEN KELLY

Stolen rocket booster

Q | A ROCKET BOOSTER THAT LAUNCHED A 1966 NASA LUNAR PROBE WAS CAPTURED BY EARTH'S GRAVITY IN NOVEMBER 2019. IT THEN ESCAPED OUR GRAVITY IN MARCH 2021. WHAT GAVE IT ENOUGH ENERGY TO ESCAPE?

R.C. Timm
Florissant, Colorado

A | The motion of the booster, named 2020 SO, is primarily driven by the gravity of the Sun and Earth. Prior to 2019, the booster was orbiting the Sun with an orbit similar to Earth's, but moving at a slower velocity relative to our planet. So, when Earth "caught up" to 2020 SO, our planet's gravity pulled the object inside Earth's Hill sphere — the region around a celestial object where its gravitational attraction dominates all other sources of gravity. Thus, Earth temporarily captured the booster from the Sun.

The overall orbital energy in the Sun-Earth-object system remains constant over time, meaning that there was no extra energy imparted to the booster at any time before capture, during the temporary Earth-orbiting phase, or after escape back into solar orbit. But the energy level of the Sun-Earth-object system does determine the regions where a satellite moves. At a given position and at a low velocity, an object is bound to either a geocentric or heliocentric orbit. It does not have enough energy to transition between either orbit. For higher velocities at the same position, two gateways open where a heliocentric orbit intersects with the Earth's Hill sphere. These specific points are known as the Lagrange L1 and L2 equilibrium points. At either gateway, a satellite orbiting the Sun could find itself briefly orbiting the Earth, and vice versa.

The orbital energy of 2020 SO was high enough for the booster to move from its heliocentric orbit through the L2 gateway into Earth's Hill sphere in November 2020, when it was temporarily captured. Since the energy of the system is conserved, the other gateway remained open to the booster and 2020 SO escaped Earth's Hill sphere through the L1 point in March 2021.

Javier Roa Vicens
Navigation Engineer, NASA's Jet Propulsion Laboratory, La Cañada Flintridge, California

Q | I'VE SEEN IT SUGGESTED THAT THE HYPOTHETICAL PLANET NINE COULD BE A BLACK HOLE FIVE TO 10 TIMES THE MASS OF EARTH. AS I UNDERSTOOD IT, HOWEVER, THE MINIMUM WEIGHT OF A BLACK HOLE IS 3 SOLAR MASSES, SO HOW COULD THE PLANET BE A BLACK HOLE?

William Jennings
Eugene, Oregon

The universe's earliest black holes may speckle the cosmos. It's even possible one is hiding within our solar system. ESO

SEND US YOUR QUESTIONS

Send your astronomy questions via email to askastro@astronomy.com, or write to Ask Astro, P.O. Box 1612, Waukesha, WI 53187. Be sure to tell us your full name and where you live. Unfortunately, we cannot answer all questions submitted.

A | Typically, black holes fall into one of three categories: stellar-mass, intermediate-mass, or supermassive. The lower limit for a stellar-mass black hole is still unclear. When a large star goes supernova, it leaves behind a remnant — either an extremely dense object, known as a neutron star, or a black hole. While astronomers still aren't sure exactly where the boundary between neutron stars and black holes lies, they suspect it is somewhere between 1.7 and 2.7 times the mass of the Sun. And the lightest black hole scientists have found is XTE J1650-500, which weighs in at just 3.8 solar masses.

But there's another type of black hole that may exist, though we haven't seen it yet: primordial black holes.

In the grand scheme of things, space is homogenous, meaning it is the same at every point. But early in the universe, just one second after the Big Bang, that likely wasn't the case. At that time, some parts of the universe were denser and hotter than others, making it possible that some of those regions collapsed into primordial black holes. Even though one second may not seem like a lot of time, depending on when exactly during that second a primordial black hole formed, its mass could be as low as 10^{-7} ounce (10^{-5} gram) or as high as 100,000 solar masses. (The merging of primordial black holes is considered a possible explanation for how supermassive black holes grew so large.)

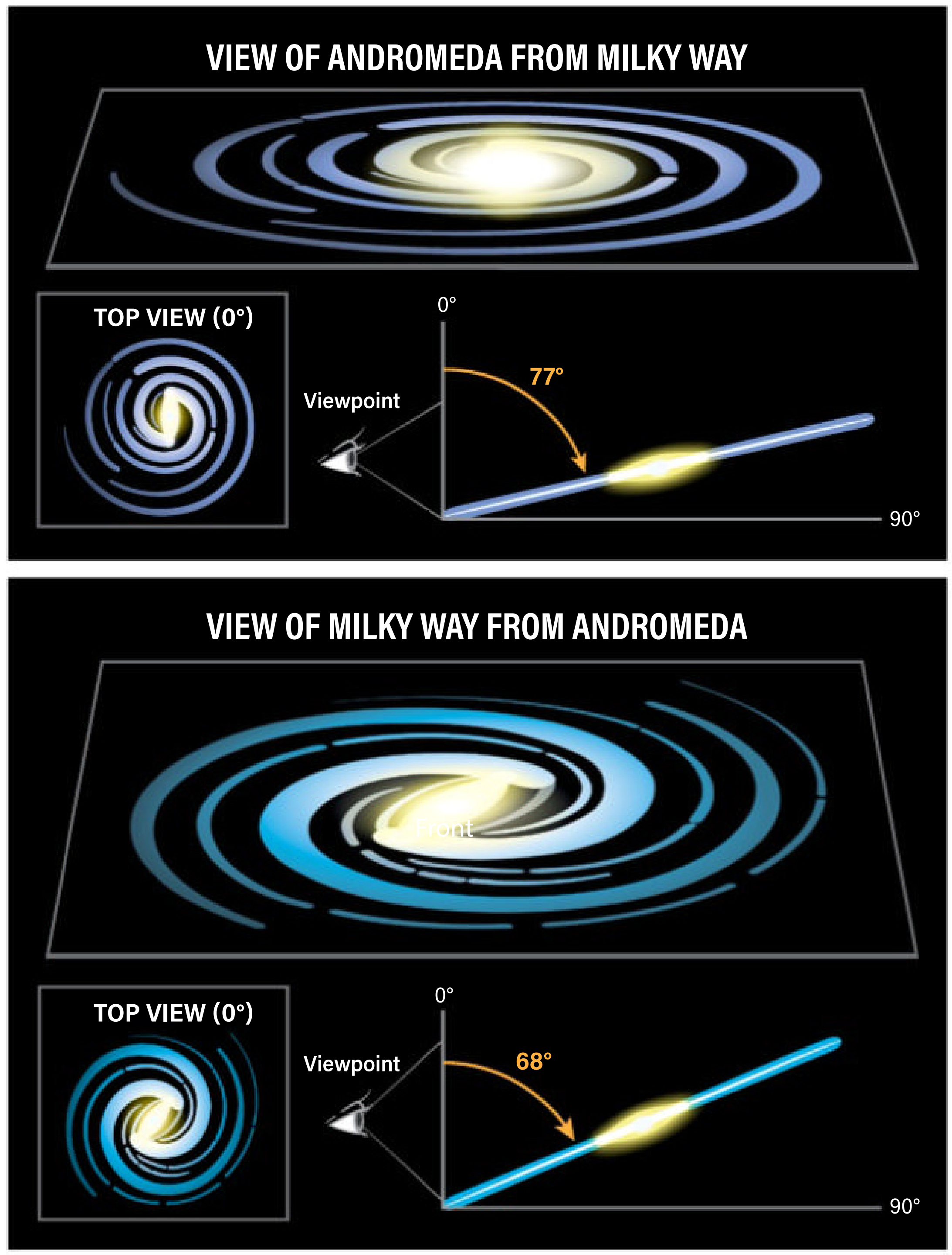
Whether or not Planet Nine exists at all is still up for debate, but if it does, it will in all likelihood be a planet instead of a black hole. Still, although the odds are small, there is a chance that a primordial black hole is hiding in our own backyard. And if it is, just imagine the new doors it would open for physics!

Caitlyn Buongiorno
Associate Editor

Q | FROM OUR PERSPECTIVE IN THE MILKY WAY, WE SEE THE ANDROMEDA GALAXY ALMOST — BUT NOT QUITE — EDGE ON. AT WHAT ANGLE DO THE INHABITANTS OF ANDROMEDA SEE OUR GALAXY?

Ralph Johnson
West Long Branch, New Jersey

A | The inclination angle of a galaxy is defined as the orientation of its stellar disk relative to the line of sight of an observer. A galaxy with an inclination angle of 90° is viewed edge-on, whereas a galaxy with an inclination angle of 0° is viewed face-on. Andromeda has an inclination angle of about 77° — meaning, as you said, we see it *nearly* edge-on.



As it turns out, any inhabitants within the Andromeda Galaxy likely get a view of the Milky Way similar to the one we have of their galaxy.
ASTRONOMY: ROEN KELLY

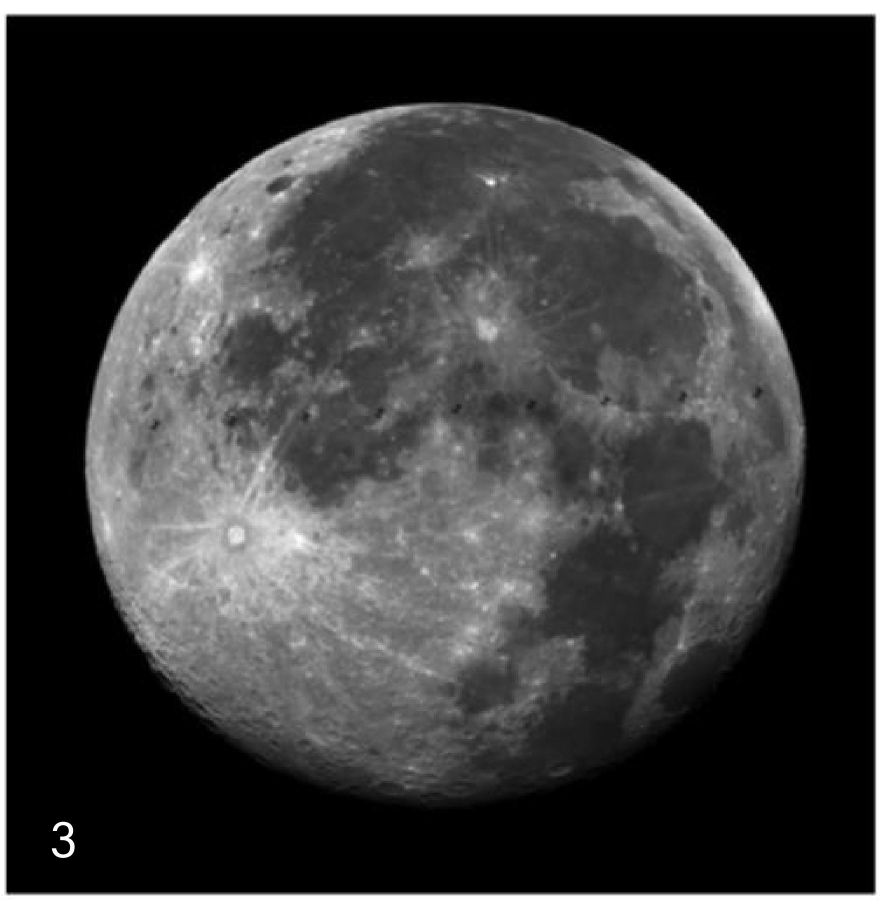
To determine the inclination angle of the Milky Way from the perspective of Andromeda, we need to know where Andromeda is located relative to the Milky Way. On a clear, dark night, the disk of the Milky Way in which we live is visible as a band of stars cutting across the sky. Turning away from the galactic center to its opposite, the anticenter — located in the constellation Auriga — you would find the Andromeda Galaxy just a bit to the west and about 2.5 million light-years away. This means that for any hypothetical inhabitants of Andromeda, their line of sight to us is close to the plane of the Milky Way's disk.

If those inhabitants also live in Andromeda's stellar disk and near the center of the galaxy, the Andromedans would see the Milky Way at an inclination angle of about 68°, similar to our view of their galaxy. This means that they would see the Milky Way close to edge-on — although not as edge-on as we in the Milky Way see Andromeda.

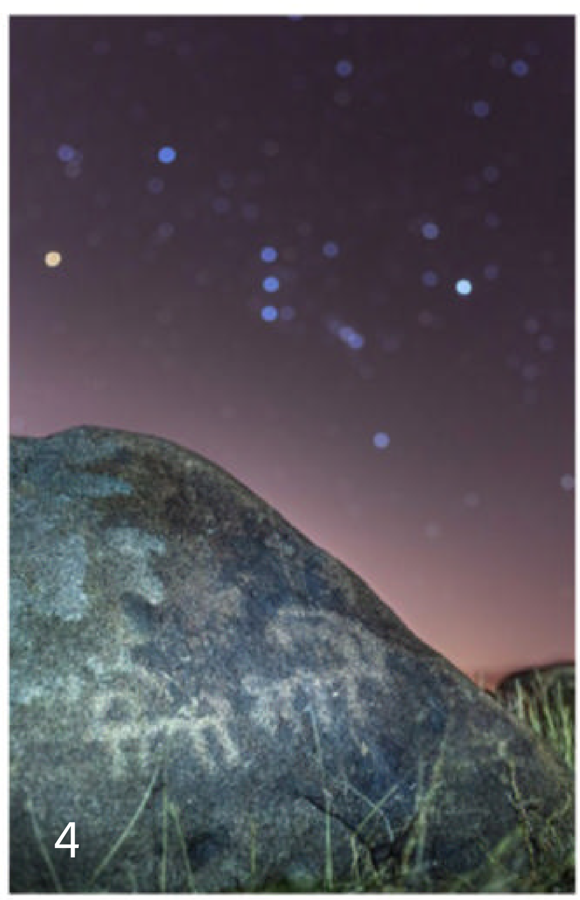
Ivanna Escala
Carnegie-Princeton Fellow, Carnegie Observatories, Pasadena, California

Cosmic portraits

2



3



4

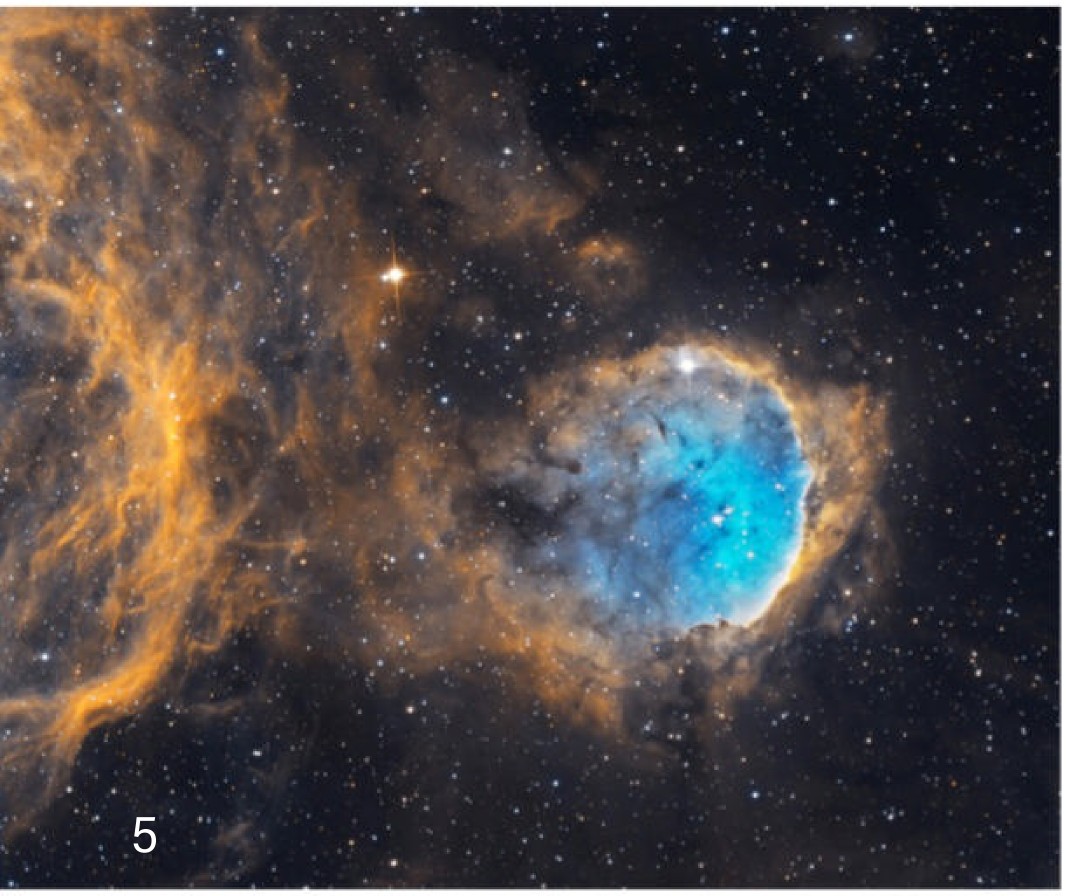
1. GOLDEN STATE
The California Nebula (NGC 1499) is dominated by red light emitted by excited hydrogen atoms. This image, combining over 31 hours of exposure, uses the Hubble palette: The strong emission in Hα, mapped to the green channel, produces a yellowish glow. **• *Douglas J. Struble***

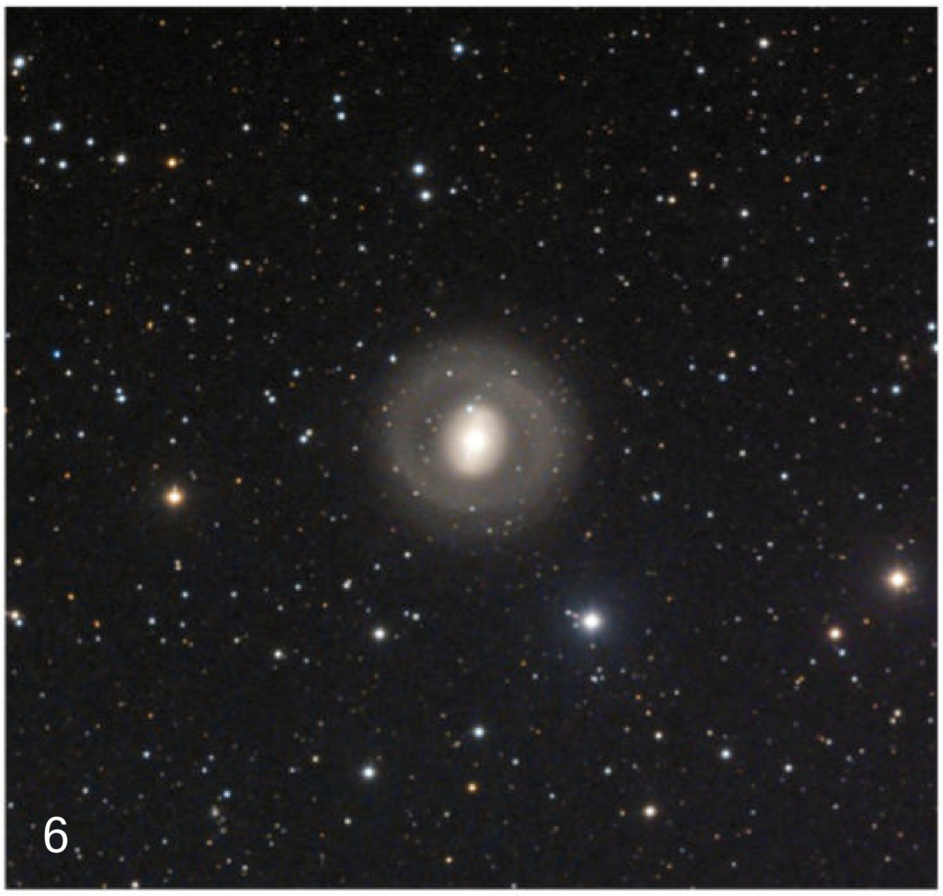
2. TWICE AS NICE
NGC 2992 (right) and NGC 2993 (left) are a pair of interacting spiral galaxies in the constellation Hydra. NGC 2992 is a Seyfert galaxy — an active galaxy with a tremendously bright core powered by a supermassive black hole. **• *Warren Keller/ Mike Selby***

3. AMBLIN' ACROSS
The International Space Station transits the Moon in this composite sequence taken Jan. 29, 2021. The photographer used a video camera and processed the image with nine frames. **• *Knox Worde***

4. HUNTER AND HUNTED
Orion looms over this shot taken in Tafresh, Iran, on Jan. 4, 2021. In the foreground lies a stone with a several-thousand-year-old petroglyph of the ibex, or wild mountain goat — a motif found throughout Iranian rock art. **• *Reihane Mohebali***

SEND YOUR IMAGES TO:
Astronomy Reader Gallery, P.O. Box 1612, Waukesha, WI 53187. Please include the date and location of the image and complete photo data: telescope, camera, filters, and exposures. Submit images by email to **readergallery@ astronomy.com.**





5. POETIC BEAUTY
In the southern constellation Carina, the emission nebula IC 2599 glows next to the open star cluster NGC 3324. The region is nicknamed the Gabriela Mistral Nebula after the Nobel Prize-winning Chilean poet. ▪ ***Russ Jacob/ Shawn Nielsen***

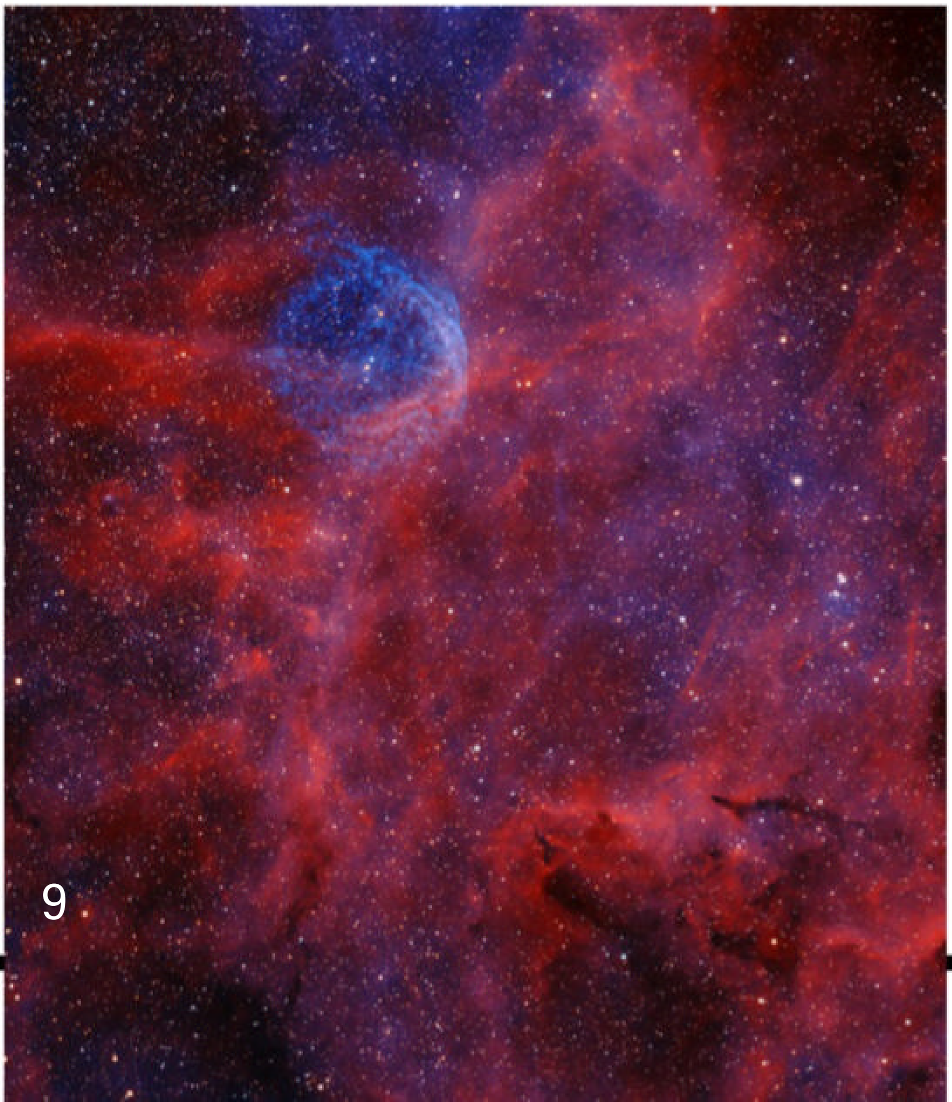
6. A RING ON IT
NGC 1291 is an unusual ring galaxy with a barred inner structure. It lies 33 million light-years away in the constellation Eridanus. This LRGB image was made with exposures of 120, 40, 40, and 40 minutes, respectively, on a 3.5-inch scope at f/6.7. ▪ ***Dan Crowson***

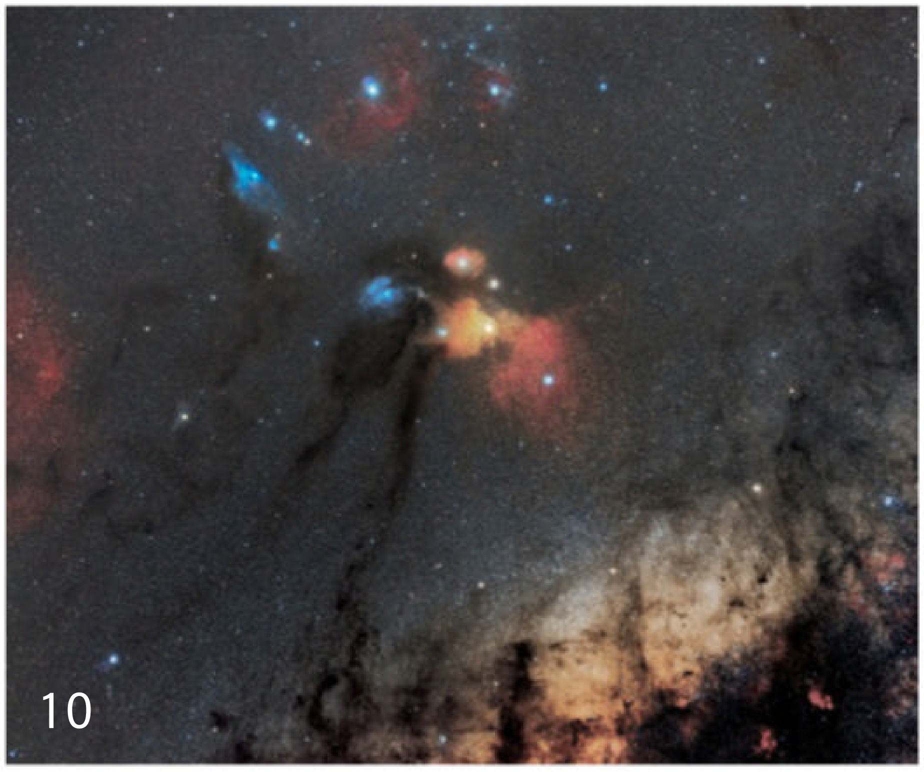
7. DRAGON DANCE
Vast tendrils of gas and dust 4,000 light-years away comprise NGC 6188 — also known as the "Fighting Dragons of Ara." In the lower right lies NGC 6164/6165, a double-lobed planetary nebula. This image, taken from Singapore, represents 38 hours of exposure with a 2.4-inch refractor at f/5.9. ▪ ***Ethan Wong***

8. COSMIC BEACON
Marshall Point Lighthouse in Port Clyde, Maine, glows under the band of the Milky Way. This 12-second shot was taken at f/4 and ISO 10,000. ▪ ***Paul Shulins***

9. SHELL SHOCKED
The Wolf-Rayet star WR 134 is so hot and massive that it is blowing its outer layers into space, forming an emission nebula as it plows into surrounding material. The shock wave is brightest along the upper right quadrant, which is often the only part of the bubble that appears in images. But a total of 34 hours of exposure — including 26.5 hours in OIII and seven and a half hours in Hα — enabled the photographer to capture the much fainter full shell. ▪ ***Alberto Ibañez***

10. A SPLASH OF COLOR
The Rho Ophiuchi Complex is a nearby star-forming region shaded by filaments. Rho (ρ) Ophiuchi itself is a binary star system shrouded by the bluish reflection nebula at center. To its right, Antares lies in the yellow reflection nebula; just above it is the distant globular cluster M4. This wide-field view was taken with a Canon 6D, a 50mm lens and just over two and a half hours of exposure. ▪ ***Fernando Menezes***





TWO SIDES OF A MULTICOLORED COIN

The two nebulae seen here — reddish NGC 2014 and its smaller bluish neighbor, NGC 2020 — may appear distinct, but they belong to the same star-forming region. Still, their colors tell two different stories. Ultraviolet radiation pouring from a cluster of hot young stars near the center of NGC 2014 stimulates nearby hydrogen, producing a ruddy hue. NGC 2020, however, owes its shape and color to a single Wolf-Rayet star at its core. This 15-solar-mass behemoth spews powerful winds that sculpt the nebula, and intense radiation that excites oxygen atoms to glow blue. The vast complex lies some 160,000 light-years from Earth in the Large Magellanic Cloud, the Milky Way's biggest satellite galaxy. NASA/ESA/STSCI


STELLARVUE
STELLARVUE SVX102D Apo on the M002CW Mount & Tripod
STELLARVUE Super-Planetary 127mm f-8 Apo on the M002CW Mount & Tripod
A master optician at Stellarvue's optical shop in California evaluates a lens that is being figured to determine how to further increase the optical accuracy to more than .99 Strehl.
America & Pelican Nebulas
zygo
Introducing the most accurate apochromatic doublet refractors we have ever made.
Stellarvue's master opticians spend up to six months figuring each objective to an optical accuracy of .99 Strehl or higher. A Zygo test report taken at full aperture is included, ensuring quality that you can see.
You deserve a truly world-class, no-compromise refractor.
STELLARVUE®
WWW.STELLARVUE.COM
11802 Kemper Rd. Auburn CA 95603
530.823.7796
SVTELESCOPES
SVTELESCOPES
STELLARVUETELESCOPES